Alternative strategies to prevent and control endoparasite diseases in organic sheep and goat farming systems
– a review of current scientific knowledge –

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Abstract

Infestation with gastro-intestinal nematodes in small ruminants can cause server economic losses and endanger animal welfare. The development of organic farming systems, the increased public awareness for drug residues in agricultural products and the development of resistant strains of parasites have enforced the search for sustainable alternatives. The aim of this paper was to provide information about endoparasite infecting small ruminants, to give an overview of the legal background and to investigate alternative control strategies and treatments, discussing them on overall viability. The main section has been divided into a part of non-chemotherapeutical control strategies and alternative anthelmintic treatments.

The conducted research has revealed the major potential to be within the field of non-chemical options. Biological control, effective pasture management, selective breeding, enhanced nutrition and the administration of bioactive forages were discussed and found to hold numerous options. The investigation of alternative anthelmintic treatments reviewed phytotherapy, homeopathy and copper-oxide wire particles. Phytotherapy was examined at in detail and found to hold future potential, indicating a strong need for scientific verification of the potential of many plants. In conclusion this paper shows possibilities and limitations in the area of alternative anthelmintic treatments as well as in non-chemical control options and outlines future research fields.

Key words: Endoparasite, small ruminants, alternative treatments

1 Introduction

Since the development from extensive to intensive agriculture, animal health problems have developed with alarming speed. In large scale sheep and goat farming systems endoparasites have been become a major threat, which is reflected in the sales figures of many countries (Coles, 2005).

Infections with gastro-intestinal nematodes can have a detrimental effect on animal health (Lüscher et al., 2005), leading to clinical and sub-clinical diseases, that may result in financial loss and overall decreased productivity (Rahmann et al., 2002).

Current large scale sheep and goat production relies heavily on the application of chemical anthelmintics. The compulsory and often excessive use of chemo-therapeutics (Hein and Harrison, 2005), often in combination with poor management practises (Wolstenholme et al., 2004), has resulted in endoparasite nematodes starting to develop resistance to treatment drugs. At present, resistant strains of endoparasites can be found all over the world, with some strains being resistant to most active agents.

Today's farmers are dealing with highly modified and specialised animals due to natural evolution and specialised trait selection as well as evolving parasites and drugs that are constantly losing efficiency. With the invention of modern anthelmintics the necessity to seek alternatives was thought to be irrelevant, as it was believed that once effective treatment had been found, these remedies would be applicable for a long time.

With the development of the organic movement aiming for more sustainable ways of farming, the search for alternatives has become necessary. The movement has developed principles for organic animal husbandry that include high levels of animal welfare. This is being achieved through keeping animals as close as possible to their natural habitat (e.g. access to grass and rangelands for maximum periods), reducing housing times and intensities, and a reducing reliance on chemo-therapy (Thamsborg and Roepstorff, 2003).

In practise these principles have meant sheep and goats are spending more time on the pasture subsequently increasing the risk of infection, through extended periods of contact with the infectious larvae of internal parasites. The restricted use of anthelmintics as a preventative has compounded the problem.

So although organic farming systems intend to avoid chemical intervention and farmer are encouraged to practise prevention rather then treatment (Rahmann et al., 2002), most organic sheep and goat farms still depend on the curative use of anthelmintic drugs.

As outlined, the realisation of these principles has proved to be difficult to achieve and the control of endoparasites in small ruminants remains a controversially discussed issue.

In conclusion, increased public awareness of drug residues in animal products, the increased resistance of parasites to modern anthelmintics, combined with the wish for a more sustainable way of farming has resulted in an intensified effort to find alternative helminth control options. Following a review by Häublein (2005) which focused on alternative parasite control in sheep, the need for further detailed examination of alternative options for parasite control was identified.

The aim of this review is to summarise the current scientific knowledge of alternative strategies to prevent and control endoparasitic diseases in organic sheep and goat farming systems.

2 Legal Background of Medical Application in Organic Farming

According to the ‘International Federation of Organic Agricultural Movements (IFOAM) Principles of Organic Agriculture’, “organic agriculture should sustain and enhance the health of soil, plant, animal, human and planet as one and indivisible” (Rahmann, 2004). Organic agriculture is seen as a way of providing healthy, high quality food that supports the holistic well being of the consumer and should therefore “avoid the use of fertilizers, pesticides, animal drugs and food additives that may have adverse health effects”. For this reason the natural resilience, resistance and vitality of animals should be supported through adequate management and housing strategies.

The statutory framework in Europe is formed by the Council Regulation (EC) No 1804/1999, supplementing Regulation (EEC) No 2092/91 on organic production of agricultural products. An excerpt from the actual wording of the law clarifies the implications on the health management of organic small ruminant farming.

The regulation changed the health management situation for organic farmers because it introduces a restriction on the permitted number of allopathic treatments that can be given before an animals loses its organic status (Keatinge et al., 2000) and it furthermore prohibits the preventive use of any allopathic veterinary medicines. In coherence with helminth control this regulation constitutes that the preventive anthelmintic treatments are prohibited, “but anthelmintics are not in the group of drugs requiring re-conversion after a specific number of treatments" (Thamsborg et al., 2004).

Younie (2000) discusses the possible future problems of this regulation in a paper presented at the 'Network for Animal Health and Welfare in Organic Agriculture' (NAHWOA) workshop and argues that there are farming situations in which the use of preventive treatments appear necessary in order to prevent animals from inescapable occurring clinical diseases for as long as there are no reliable alternative measures to control e.g. internal parasites.

Keatinge et al. (2000) fear that such a regulation might keep farmers from adequate treatment to preserve their livestock's organic status.

5. Disease prevention and veterinary treatment

5.3. If, despite all of the above preventive measures, an animal becomes sick or injured, it must be treated immediately, if necessary in isolation, and in suitable housing.

5.4. The use of veterinary medicinal products in organic farming shall comply with the following principles:

(a) Phytotherapeutic (e.g. plant extracts (excluding antibiotics), essences, etc.), homeopathic products (e.g. plant, animal or mineral substances) and trace elements and products listed in Part C, section 3 of Annex II, shall be used in preference to chemically-synthesised allopathic veterinary medicinal products or antibiotics, provided that their therapeutic effect is effective for the species of animal, and the condition for which the treatment is intended;

(b) If the use of the above products should not prove, or is unlikely to be, effective in combating illness or injury, and treatment is essential to avoid suffering or distress to the animal, chemically-synthesised allopathic veterinary medicinal products or antibiotics may be used under the responsibility of a veterinarian;

(c) The use of chemically synthesised allopathic veterinary medicinal products or antibiotics for preventive treatments is prohibited;

5.8. With the exception of vaccinations, treatments for parasites and any compulsory eradication schemes established by Member States, where an animal or group of animals receive more than two or a maximum of three courses of treatments with chemically-synthesised allopathic veterinary medicinal products or antibiotics within one year (or more than one course of treatment if their productive lifecycle is less than one year) the livestock concerned, or produce derived from them, may not be sold as being products produced in accordance with this Regulation, and the livestock must undergo the conversion periods laid down in Section 2 of this Annex, subject to the agreement of the inspection authority or body.

Figure 1. **Council Regulation (EC) No 1804/1999**

Since the introduction of this regulation almost six years have gone by, and although the situation has gradually changed, there is still a great dependence on allopathic medicine in the parasite control practices on organic farms (Thamsborg et al., 2004). However, a lot of research has been done and continues to be undertaken into effective alternative control measures like the use of improved management practices, biological control agents and bioactive forages, all which will be discussed in the following chapter.

3 Internal Parasites of Sheep and Goats

The summary information on endoparasites was taken from two standard works on veterinarian parasitology (Kassai, 1999; Rommel et al., 2000) and one on sheep diseases (Behrens, 1987) (Table 1). Information contained about immunity is based on the physiological processes within sheep and cannot generally be transferred to goats due to their greater susceptibility to nematode infections. For goats it can take at least two summers to acquire effective immunity (Thamsborg et al., 2004).

Table 1. Worldwide occurring helminths in sheep and goats (Behrens, 1987; Kassai, 1999; Rommel et al., 2000)

Phylum	**Plathyhelminthes – Flatworms**		
Class	**Digene - Flukes**		
Order	ECHINOSTOMIDA		
Genus	**Causative Organism**	**Disease**	**Distribution**
Fasciola	*Fasciola hepatica* *Fasciola gigantica*	Fasciolosis/ Liver fluke disease/ Hepatic distomatosis	worldwide
	Fascioloides magna	Fascioloidosis/ Large American liver fluke disease	North America, endemic in central Europe, occurs in Mexico/ South Africa
	Fasciolopsis buski	Fasciolopsiosis	South and East Asia
Order	AMPHISTOMIDA		
Genera	**Causative Organism**	**Disease**	**Distribution**
Paramphistomum, Caulicophoron et al.	*e.g. Paramphistomum cervi, Caulicophoron daubneyi…*	Paramphistomatidosis/ Rumen fluke disease/ Ruminal amphistomidosis	Worldwide, in grazing animals
Order	PLAGIORCHIIDA		
Genera	**Causative Organism**	**Disease**	**Distribution**
Dicrocoelium	*Dicrocoelium dendriticum*	Dicrocoeliosis/ Lanceolate fluke disease	Worldwide, in grazing animals, except Australia
Eurytrema	*Eurytrema pancreaticum, Eurytrema coelomaticum*	Pancreatic fluke disease of ruminants	South-East Asia, India, China, South America
Order	STRIGEATIDA		
Genus	**Causative Organism**	**Disease**	**Distribution**
Schistosoma	*Schistosoma bovis, S. indicum, et al.*	Schistosomatidosis/ Blood fluke disease	Africa, Middle East, Asia, South Europe
Class	**Cestoda – Tapeworms**		
Order	CYCLOPHYLLIDEA		
Genera	**Causative Organism**	**Disease**	**Distribution**
Monezia et al.	*Moniezia expansa, Moniezia benedeni, et al.*	Tapeworm disease/ Cestodoses/ Moneziosis	Worldwide, in grazing animals
Cysticercus Coenurus	*Cysticercus ovis, C. tenuicollis; Coenurus cerebralis, C.skjabini; All larvae of canine tapeworm species Taenia*	Ovine Cystercosis/ Sheep measles	Worldwide, sporadic in Europe
Echinococcus	*Echinicoccus cysticus (hydatidosus)*	Cystic echinococcosis/ Hydatidosis/ Hydatid disease	Worldwide
Phylum	**Nemathelminthes - Roundworms**		
Class	**Nematoda - Threadworms**		
Order	RHABDITIDA		
Genus	**Causative Organism**	**Disease**	**Distribution**
Strongyloides	*Strongyloides papillosus*	Strongyloidosis of ruminants	Worldwide especially in the humid tropics

Table 2 (continued). Worldwide occurring helminths in sheep and goats (Behrens, 1987; Kassai, 1999; Rommel et al., 2000)

Order	STRONGYLIDA		
Genera	**Causative Organism**	**Disease**	**Distribution**
Oesophagostomum	*Oesophagostomum columbianum, O. venulosum*	Oesophagostomosis/ Nodular worm disease	More prevalent in warm and humid regions
Chabertia	*Chabertia ovis*	Chabertiosis	Worldwide, more prevalent in temperate climates
Bunostomum, Gaigeria	*Bunostomum trigonocephalum, Gaigeria pachyscelis*	Bunostomosis/ Hookworm disease	Worldwide
Mammomonogamus	*Mammomonogamus laryngeus, M. nasicola*	Mammomonogamosis/ Syngamidosis of mammals	Endemic in tropical/ subtropical areas of Africa, America, Asia
Cooperia Haemonchus Nematodirus Ostertagia Trichostrongylus	*Large variety, refer to table 2*	Trichstrongylidosis Diseases predominantly or solemnly caused by one species are then called after the genus	Worldwide, most common species in grazing ruminants
Dictyocaulus	*Dictyocaulus filaria*	Dictycaulosis/ Prasitic bronchitis	Prevalent in temperate regions
Protostrongylus, Cystocaulus, Muellerius, Neostrongylus, Varestrongylus	*Protostrongylus infescens, Cystocaulus ocreatus, Muellerius capillaris, Neostrongylus linearis, Varestrongylus capreoli*	Protostrongylidosis/ Nodular lungworm disease	Worldwide, particularly in arid- and semi-arid regions
Order	ASCARIDIA		
Genera	**Causativ Organism**	**Disease**	**Distribution**
Ascaris, Toxocara	*Ascaris suum, Toxocara vitulorum*	Ascaridiosis/ Roundworm diseases	Worldwide, particularly in the tropics
Order	SPIRURIDA		
Genus	**Causative Organism**	**Disease**	**Distribution**
Thelazia	*Thelazia rhodesi, T.gulosa, T. skrjabini*	Thelaziosis/ Eyeworm disease	Worldwide
Elaeophara	*Elaeophara schneideri*	Elaeophoris	North America
Order	ENOPLIDA		
Genus	**Causative Organism**	**Disease**	**Distribution**
Trichuris	*Trichuris ovis, T. capreoli, T. skrjabini*	Trichuroisis/ Whipworm disease	Worldwide
Capillaria	*Capillaria bovis, C. longipes*	Capillariosis	worldwide

4 Biological Control of Endoparasites

The principle of this strategy bases on the rule that all species of animal are regulated by other living organisms to prevent the uncontrolled increase of one population (Grønvold et al., 1996). In the context of parasite control it usually means the use of a naturally occurring antagonist to lower a pest population which would otherwise cause losses to animal production. Grønvold et al. (1996) conclude that of all possible antagonistic organisms only nematophagous fungi, earthworms and dung beetles have realistic potential as biological control agents, although there are several species that little or nothing is known about and therefore their potential use for biological control cannot be assessed/estimated.

4.1 Earthworms

Earthworms are soil inhabitants that live on organic matter deposited on the soil surface. Organic matter gets pulled down below the surface either for food or to plug the earthworms burrows. Therefore the major contribution of earthworms towards the biological control of nematodes is seen in the destruction of eggs and larvae by digesting them or transferring them to deeper levels of the soil where chances that they can reach the surface as infective larvae are very low (Persson, 1974 in: Grønvold et al., 1996). A New Zealand study examined the ability of mixed earthworm populations, alone or in combination with other biological control organisms to reduce pasture infectivity in two experiments (spring and autumn) (Waghorn et al., 2002). "Earthworms reduced the total number of larvae recovered in both trials and the number recovered from herbage in trial 1."

4.2 Dung Beetles

The term 'dung beetle' refers to those beetles that live partly or exclusively on the dung of herbivorous; most species belong to the family *Scarabaeidae*. Adult beetles use the liquid contents of manure for their nourishment and some species form dung balls which they bury and lay their eggs in, others just live in the manure pats (Thomas, 2001). The activity of dung beetles is being discussed controversially: by breaking up the pats and partially burying the manure, they enhance the drying up of the dung which deteriorates growing conditions for larvae (Grønvold et al., 1996) but by the same activities in bad weather conditions they might help the larvae to survive by airing out the pats and thereby providing oxygen to the larvae.

Bryan (1973/1976) was able to show in his experiments with manure pats and dung beetles that dung beetles can reduce larvae on herbage in between 40 to 93%, the percentage of reduction correlated positively with the number of beetles. Bryan also found out that the burial of dung containing larvae contributed to their longevity and he concluded that the burial can create a favourable environment for larval development because they are protected from extreme climatic conditions (Bryan, 1973 and 1976). Waghorn et al. (2002) also confirmed the influence of dung burial in respect to larval development with the result of significantly more larval recoveries than when dung was not buried, although dung was manually buried in order to mimic the natural activities of the dung beetle. Vlassoff et al. (2001) also mention that results of studies with dung beetles have been variable, some species reduce and others increase larval numbers (Fincher, 1973).

4.3 Nematophagous Fungi

In this special case, it means the use of the naturally occurring nematophagous or nematode-destroying fungi to control parasitic nematodes in ruminants. Nematophagous fungi are soil inhabitants and can be found in most soil types throughout the world. Research has shown they are found more frequently in organic production systems than any other (Jansson et al., 2004).

The fungi can be divided into groups depending on their mode of affecting nematodes: there are nematode trapping, endoparasitic, egg and female parasitic and toxin producing fungi (Jansson et al., 1997). The fungi of the nematode trapping group all have in common that they form a vegetative hyphal system that produces trapping organs such as sticky nets, knobs or rings (Hertzberg et al., 2002). When for example a nematode gets trapped, the fungi penetrate the nematode cuticle with their hyphae that then grow out and fill the body of the nematode to finally digest it (Grønvold et al., 1996).

The idea of using nematophagous fungi to control parasitic nematodes is based on the reduction of the larval level in the faeces before larvae reach the vegetation, which requires a high density of spores in the faeces. There are two possible ways to reach that high spore density, the first is to artificially inoculate the faeces and the second way is to administer the spores orally. Since the first way seems not viable the only possibility was to discover those fungi that are able to survive the gastro-intestinal tract of ruminants. This complex problem may have been one reason for the rather slow progress of science concerning this topic.

Research had started as early as in the 1940's but with little success at the time (Hertzberg et al., 2002). In the 1960's there was evidence found for predaceous fungi working against parasitic nematodes (Parnell and Gordon, 1963), but these experiments were not continued. The major breakthrough was achieved at the beginning of the 1990's when Larsen et al. (1991) selected fungi that were able to survive in vitro conditions simulating the passage through the gastro-intestinal tract of cattle. The two genera tested, *Arthrobotrys* and *Duddingtonia*, both showed the ability for survival with the genus *Duddingtonia* performing significantly better, 87.5% versus 46% (Larsen et al., 1991). These results were the final trigger for detailed research in this area and since then many trials have been undertaken in several countries in which faecal samples of sheep have been screened for predacious fungi (Larsen et al, 1994; Hay et al., 1997; Ghahfarokhi et al., 2004). Even after the promising results of the feeding trials with *Duddingtonia flagrans* (Wolstrup et al., 1994; Githigia et al., 1997; Faedo et al., 1998) science continued to research a wider range of fungi until the end of the 1990's when trials with fungi other than *Duddingtonia flagrans* started to decrease.

From the year 2000 onwards most scientists started to focus on the potential of *D. flagrans*. One of the first questions that occurred in that context was whether or not *D. flagrans* had the ability to grow beyond faeces into the surrounding soil and by doing so it could control emerging third stage larvae from eggs deposited prior or post deposition of fungal spores (Faedo et al., 2000). The results confirmed that *D. flagrans* significantly reduces the number of infective larvae that migrate onto the pasture and it also showed that there was no effect on larval migration of prior and post deposited faeces. In the first years, most of in vivo trials focused on the potential of larval reduction by the fungus and either there was little knowledge about the amount of chlamydospors necessary for a successful reduction nor it was clear if the larvae of different species would be affected in the same way.

After the excretion of the spores the faeces get colonized by the *Duddingtonia* mycel. Excretion density of the spores and growth rate of the mycel correlates positively (Hertzberg et al., 2002). *D. flagrans* is a fungus that produces trapping nets and the presence of any nematodes induces the trap production, which lasts for approx. 2-3 weeks (Gronvold et al., 1996). The optimum temperature for the development of trapping nets is 30°C; a rise in temperature to 35°C or more causes any fungus activity to stop and a fall in temperature to below 10°C reduces the trapping ability (Gronvold et al., 1996). The trials used spore numbers in between $3x10^5$ and $5x10^7$ chlamydospores per day, some dosed it per kilogram bodyweight (Githigia et al., 1997; Larsen et al., 1998; Faedo et al., 2000), and others administered a set dose per sheep per day (Faedo et al., 1998; Knox and Faedo, 2001; Waller et al., 2001ab). Dose trials from Pêna et al. in 2002 showed that there was no significant difference in a dose between $1x10^5$ and $1x10^6$ spores/ kg BodyWeight (BW)/ day, with every dose above $1x10^4$ successfully reducing the larval development by more than 90%. Chandrawathani et al. 2003 experimented with 1.25, 2.5 and $5x10^5$ spores/ kg liveweight / day and found that a reduction >99% of larval recovery was only achieved with $2.5X10^5$ or more.

For a successful application of the fungus treatment a feasible way of administration should be integrated into the everyday farming routine. Most studies in the last years administered the spores within a daily supplement ration (Fontenot et al., 2003; Chandrawathani et al., 2004; Waller et al., 2004) although Waller et al. had investigated the potential ways of administration in 2 studies in 2001. These studies showed that feedblock formulations and a 'fungal controlled release device' (CRD's) could have some potential but no further investigation has been conducted since then.

4.3.1 Sheep

Githigia et al. (1997) were the first to assess the preventative effects of *D. flagrans* under field conditions in lambs and their results were the first to show varying possibilities and potential limitations with the use of *D. flagrans* under field conditions. The results showed that sub-clinically infected lambs grazed on contaminated pasture, fungus feeding does not eliminate the risk of severe infection and can consequently only be applied on uninfected animals and clean pastures.

Within the framework of the EU-project called 'Worm control in organic production systems for small ruminants (WORMCOPS) a series of field trials have been conducted in Northern Europe to assess the performance of *D. flagrans* in two different management systems (animals either set-stocked or moved regularly) (Larsen and Thamsborg, 2005). The experiments in Denmark and in the UK observed the applicability of *D. falgrans* in set-stocked farming systems in the time from 2002 to 2004 and both trials had rather disillusioning results:

- At times there was a lack of any beneficial effects
- Unreliability in the control of Nematodirus ssp.
- Animals needed either de-worming or moving to clean pastures to survive the trials
- Administered supplement was only slowly accepted
- No or insignificantly reduced pasture infectivity

Experiments in Sweden investigated the effects of *D. flagrans* under commercial farming conditions where animals were moved a number of time during the season (Waller et al., 2004).

The evaluation of *D. flagrans* on the two farms in Sweden from 2001 to 2003 was the only set of trials that had an overall positive result: All ewes were de-wormed before turnout in these experiments and went to naturally infected paddocks receiving supplement with or without fungus. Faecal egg counts and worm burdens were comparatively low throughout the evaluated time, indicating that the farms had had reasonably good helminths control strategies anyway (Waller et al., 2004). The trials resulted in a significant difference between the fungus and the control groups because more lambs of the fungus groups reached the marketable weight faster and the ones that did not still showed a comparatively higher average body weight.

Contrary to these results were the results from studies conducted in the Netherlands in 2002 and 2003: Although the sheep were moved at 3 week intervals no useful effects could be observed (Larsen and Thamsborg, 2005).

At the same time there was another field trial undertaken in Northern Germany that was independent from WORMCOPS. The trial investigated the influence of *D. flagrans* on the infection risk for sheep and goats under set-stocked conditions (Holst, 2005). In this trial infected and uninfected sheep were moved to contaminated pastures. Throughout the whole time there were no significant differences in faecal egg counts or pasture infectivity between control and fungus receiving sheep. Several animals from both groups had to be treated due to clinical signs of PGE during the first months and at after approx. 4 months all animals were treated with Levamisol to prevent further severe infections and losses. To sum up the results there was no indication given that treating sheep with fungal spores can prevent serious infection or significantly reduces pasture infectivity.

Another field trial that was undertaken in Malaysia showed very good results for *D. flagrans* in combination with rapid rotationally grazing (Chandrawathani et al., 2004). The experiment observed the potential of the fungus to reduce pasture infectivity, which was proved by significantly lower mean tracer faecal egg counts in the fungus treated groups and by the significantly better growing rates for lambs.

4.3.2 Goats

Several studies have been carried out which dealt with the possibilities of the administration of *D. flagrans* spores to goats; however these have consisted of a limited number of field trials. As with studies concerning sheep there seems to be the same discrepancy between conclusions based on short-term trials under experimental conditions (Paraud et al., 2003; Waghorn et al., 2003; Terill et al., 2004; Paraud et al., 2006) and the applicability under field conditions (Holst, 2005; Chartier and Paraud, 2005).

All the studies that were conducted under experimental conditions show positive results, where the reduction of larval development ranged from 40.4% to 89% (Wagehorn et al., 2003), 60.8% to 93.6% (Terill et al., 2004), 62.8% to 99.5% (Paraud et al., 2006).

In contrast to these results Holst (2005) observed no significant larval reduction due to *D. flagrans* under field conditions. Differences between fungus and control groups only occurred from the end of July to the beginning of September, when all animals had been treated with anthelmintics due to severe infections, but these differences were not significant enough to testify the effectiveness of *D. flagrans* in goats under field conditions.

Paraud and Chartier (2005) mentioned on going field trials in France that have indicated similar levels of infection and growth for fungus and control groups but with a more than 80% reduction in larval development in the faeces of the fungus group. Unfortunately further or more detailed information on these trials could not be found.

5 Controlling helminths through effective pasture management

Understanding the influence of pasture management on the internal parasite control possibly starts with detailed epidemiological knowledge of the development of the parasites in and outside their hosts (Table 2). What varies with different climates is the larval development outside the host and therefore no reliable statement can be made for larval availability and survival that applies to all climates. That is why the following points should be considered when attempting to control internal parasites on the pasture.

Larval availability and survival on pasture (Barger, 1999):

- the intake of infective larvae will be proportional to the concentration of infective larvae on herbage
- if larval availability is observed over a longer period of time, peak and troughs will be discovered and once peaks are known, the optimal timing of control measures can be determined
- searching the origin of a peak is necessary for further prevention
- Larval survival is different for each climate and it is essential to know reasonably exact survival times for the estimation of a substantial decline in pasture infectivity

As an example Uriarte et al. (2003) studied the seasonal changes of parasitic nematode burdens in sheep and identified three generations of parasites during the experiment (approx. one year). The first generation derived from larvae inhibited within the animals that continued their development in spring. The next generation resulted from the over-wintering absorbed larvae on the pasture and was the most important source of newly acquired infections in lambs, often leading to clinical symptoms.

Table 2. Summary of all helminths parasitizing the gastro-intestinal tract (Behrens, 1987; Kassai, 1999; Rommel et al., 2000; Vlassow et al., 2001; Winkelmann, 2005)

Disease	Genus and species	Common name	Site	Prepatent period	Longevity*	Optimal temp.
Cooperiosis	Cooperia curticei, C. oncophora	Small intestinal worm	Small intestine	15-18 days	Several months	20-25°C
Haemonchosis	Haemonchus contorus H. placei , H. similis	Barber's pole/ Twisted stomach/ Wireworm	Aboma-sum	2-4 weeks	Eggs need warm/ moist conditions then they live for some weeks	20-25°C
ematodirosis	Nematodirus battus N. fillicolis, N. furcatus, N. helvetianus, N. spathinger	Thread-necked worm	Small intestine	N. battus 15 days N. helvet. 20-26 days	Eggs survive for one year and longer, they can overwinter, once hatched they live for approx. 3 weeks	20-25°C
Ostertagiosis	Ostertagia ostertagi O./ Teledorsagia circumcincta, O. crimensis, O. leptospicularis, O. pinnata, O. trifucata	Medium brown stomach worm	Aboma-sum	17-28 days	several months, survives mild winters	20-25°C
Tricho-strongylosis	Trichstrongylus aexi, T. capricola, T. colubriformis, T. rugatus, T. vitrinus	Bankrupted worm	Small intestine	2-4 weeks	Several months	20-25°C
Monieziosis/ Tapeworm disease/ Cestodoses	Moniezia benedeni, M. expansa	Tapeworm	Duode-num	30-52 days	Survival of the infected interm. host 1,5-2 years	Develop. at 28°C in interm. Host in 4 weeks
Cystic echinococcosis/ Hydatidosis/ Hydatid disease	Echinicoccus cysticus (hydatidosus)	Tapeworm hydatid	Various inner organs	1.5-2 years, sometimes less	No data available	
Strongyloidosis	Strongoloides papillosus	Dwarf thread worm	Small intestine, lungs, skin	9-14 days	Larvae max. 4 months	> 10°C 20°C opt.
Oeso-phagostomosis/ Nodular worm disease	Oesophagostomum columbianum O. venulosum	Nodular worm	Small intestine, colon	45 days approx.	6 months or more	Ca. 25°C
Chabertiosis	Chabertia ovis	/	Small intestine, colon, rectum	5-7 weeks	Larvae 6-8 weeks in summer	Ca. 25°C
Bunostomosis/ Hookworm disease	Bunostomum trigonocephalum	Hook worm	Skin, lungs, small intestine	7 weeks	Eggs 1-2 years Larvae 7 weeks in summer	20-30°C
Paramphistoma tidosis/ Rumen fluke disease	Paramphistomum cervi, Caulicophoron daubneyi…	Rumen fluke	Duode-num, rumen	14 weeks approx.	Up to 6 months in temperatures <10°C	Develop. at 16-17°C in interm. host In 110 days

* Longevity can vary greatly depending on climatic conditions, particularly temperature and humidity

The last generation that was observed in autumn had little impact on the animals but was identified as the main source of pasture contamination for the following season. This experiment shows the applicability of the above-mentioned points and the importance of epidemiological knowledge for successful grazing management.

In context with grazing management and epidemiological knowledge the two terms 'safe' and 'clean' pasture are often referred to and it seems advisable to explain them to avoid misunderstandings.

'Clean' pasture is the expression for a pasture with a nil or very low infection risk when animals are firstly grazed on it (Younie et al., 2004), this is achieved by a three year rotation between a susceptible species, an unsusceptible species and the use of the land for forage or crops (Thamsborg et al., 2004).

'Safe' pastures are referred to those that are minimally contaminated. It takes approximately 3 to 9 months for pasture infectivity to decrease significantly for most species, depending on the climate and time of the year (Barger et al., 1999), an exception are certainly Nematodirus ssp. whose eggs are able to survive on pasture for more than a year (Younie et al., 2004).

In Northern European conditions a pasture can be considered safe if it meets the following criteria (Thamsborg et al., 2004)

SPRING

1. Pastures that have not been grazed by small ruminants in the last grazing season
2. Pastures that have not been grazed by small ruminants since midsummer of the previous year are safe all nematode species except for Nematodirus ssp.

SUMMER AND AUTUMN

1. Pastures last grazed in autumn of the previous year that have not been grazed in spring the following year
2. Pastures that have not been grazed for 3 months during summer are safe except for Nematodirus ssp.

In this context it is not only necessary to know about the time frames for safe pastures to keep pasture contamination at a low level, it is as important to know for which period of time animals can remain on the pasture until the next generation of infective larvae has developed, which is shown in Table 3.

Table 3. Guideline for contamination of safe pasture in temperate climates (Thamsborg et al., 2004; Eysker et al., 2005)

	Spring	Summer/ Autumn
Infected animals	Up to 6 weeks	2 – 3 weeks
Uninfected animals	Approx. 8 – 12 weeks (Mid June)	At least 6 weeks

5.1 Climatic Conditions

The particular climate of an area always influences the grazing management because egg hatching and larval development both depend on prevailing climatic conditions (Barger, 1999). Larval survival times can range from some weeks in the wet tropics (Banks et al.,

1990) to more than a year in temperate climates (Barger 1984). For this reason there is no universally applicable grazing system that regulates pasture infectivity in every climate.

For example a grazing system that has proved to be reliable for parasite control in the tropics is referred to as “rotational grazing” (Barger, 1999). This system is based on rapid pasture movement (every 3-4 days) to provide safe pasture, followed by longer periods of spelling (30+ days) based on the duration of the parasite cycle (infective larvae develop and die within 4-6 weeks in the tropics) (Chandrawhathani et al., 2004).

Rotational grazing has already proved its efficiency in the tropics (Chandrawathani et al., 2004) but it cannot be applied to temperate climates for several reasons, one of which is the long amount of time for pasture to become safe again (Barger, 1999). In Table 3 the guidelines for contamination of safe pasture in temperate climates are shown and can be used to develop moving strategies.

The Mediterranean climate comprises various sub climates that lead to a great diversity in this area and to two basic differences in management strategies (Thamsborg et al., 2004). The main difference is whether there is a break in the middle of the grazing season (Dry lands/ Transhumance) or not (Irrigated lands).

5.2 Grazing system and herd management in respect to control strategies

There are basically two different types of grazing systems and three different types of management. Grazing systems differ in the stock movement frequency; this can vary from no movement at all to frequent changes between pastures. In the case of no movement animals remain on the same pasture for the whole grazing season (set-stocked). Both grazing systems have advantages and disadvantages but in terms of parasite control it is easy to imagine that sub-clinically infected animals that stay within the same area for a complete season keep contaminating the pasture continuously and by doing that they constantly increase the infection risk for uninfected animals.

In terms of different management strategies there are organic, integrated and conventional ways of managing a farm, which principles are assumed to be known and therefore won’t be discussed in detail.

An interesting fact in this context that appears to be worth mentioning is the influence of the management strategy on parasite diversity. A French study that conducted investigations into the impact of management strategy on the parasite diversity found that organic farms have a significant higher diversity of parasites on pastures and in infected animals (Cabaret et al., 2002a). A further study that researched the relationship between diversity and intensity of infection in dairy goats detected that intensity of infection was negatively correlated with helminths diversity (Silvestre et al., 2000).

The main function of any grazing system is to provide safe/ clean pastures on which animals can safely graze as well as sufficient forage availability for grazing animals (Barger, 1999). In order to control gastro-intestinal nematodes through grazing management three strategies can be categorized as measures to minimize new and re-infection (Barger, 1997; Thamsborg et al., 1999; Younie et al., 2004). The three categories are ‘preventive strategies’, ‘evasive strategies’ and ‘diluting strategies’ and they are summarized in Table 4.

Studies in France and in Denmark (Bouilhol and Mage, 2001; Githigia et al., 2001) highlighted in their results how important a well thought-out grazing system is. The French survey analysed different management concepts for organic meat sheep farms and found that concepts were varying in (1) time of lambing and (2) management for weaners (moved to either infected or uninfected pastures). The first important outcome of this survey was that early lambing appears to be the key for sufficient weight gain because it uses the seasonal plant growth to full capacity (Bouilhol and Mage, 2001). Their other finding confirms that moving weaners to safe pastures is a successful measure for parasite control.

Table 4. Overview of different grazing management strategies (Barger, 1997; Cabaret et al., 2002b, Thamsborg et al., 1999; Younie et al., 2004)

Preventive Strategies	Evasive Strategies	Diluting Strategies
Turning out parasite free animals on clean pastures	*Worm challenge is evaded by moving animals from contaminated to clean pasture*	*Worm challenge is relieved by diluting pasture infectivity*
⇨ *Delayed turnout* ⇨ Changing pastures between seasons ⇨ Moving at weaning ⇨ Late lambing ⇨ Grass reseeds ⇨ Cultivation of annual forge crops ⇨ Silage/ hay aftermaths ⇨ Alternation of different host species	⇨ *Moving to safe pastures within the same season* ⇨ Alternate grazing of different species ⇨ Hay/silage aftermaths ⇨ New grass reseeds ⇨ Cultivation of annual forage crops	⇨ *Avoid stocking rates close to carrying capacity of plant production* ⇨ *Reduction of the general stocking rate* ⇨ Mixed grazing with other host species ⇨ Alternate grazing with other host species ⇨ Mixed grazing with other age groups

In the Danish experiment the 'dose and move' strategy was compared to a 'move only' strategy (from an infected to a clean pasture) for lambs at weaning time. As a result acute parasitic gastroenteritis could be prevented and weight gains were comparable for all groups, although pasture contamination was higher on the pastures that had been grazed by the 'move only' group (Githigia et al., 2001).

5.3 Stocking Rate and Animal Behaviour

The base for successful parasite control in small ruminants is to keep the pasture infection level low so that the animals are not exposed to an excessive larval population on the pasture. A further fact that may be considered in this context is the possible correlation between actual migration height of infective larvae and stocking rate. Research results appear dissonant and controversial in this particular question. While one source states that the majority of larvae usually "crawl only one inch from the ground onto herbage, so not allowing animals to graze below that point will cut down a lot of infestation" (Wells, 1999). Another source writes that about 80% of the infective larvae can be found on the first two inches of vegetation, so avoiding grazing to below this level will reduce problems (Schoenian, 2005). On the other hand Thamsborg et al. (1996) argue that a reduced plant cover can as well create condition less favourable for larval development and that faecal deposits on short grass result in significantly reduced infective larvae on the surrounding pasture (Secher et al., 1992)

Although the correlation between stocking rate and parasite infestation is mentioned, only two studies could be found in the run-up of the literature inquiry.

Thamsborg et al. (1996) investigated the influence of an increasing stocking rate on nematode infection rate in sheep in an experiment. Their results demonstrated that the stocking rate has a rather long term effect than short term consequences because only little differences were observed in the first year whereas higher levels of infection, related to an increased stocking rate, were confirmed for the second year of the experiment.

A more recent study investigated the relationship between nematode infections and general farming aspects and characteristics on 20 French dairy goat farms (Vallade et al., 2000). In this survey those farms that needed the fewest annual anthelmintic treatments either fed supplements or had a reduced stocking rate. While Vallade et al. see a clear connection, Thamsborg et al. (1996) assume that the relationship between stocking rate and infection level is neither strong nor consistent but is very complex.

This complex relationship could originate from the fact that larval intake is not simply determined by pasture contamination but by a living organism which has a foraging strategy that might protect itself from the excessive intake of parasites “Ruminants are known to avoid grazing herbage which is contaminated with faeces” (Hutchings et al., 1998). Cooper et al. (2000) concluded in their experiments that sheep generally prefer grazing uncontaminated patches of pasture and that the presence of faeces enables sheep to detect and avoid contaminated patches. Further on in the experiment sheep generally appeared to consume fewer larvae than were present on herbage and infected sheep consumed more larvae than uninfected ones. The authors conclude that “parasite infection status and faecal distribution influence grazing behaviour and rate of infective larvae consumption”.

A study that was conducted in context with nutrition found that grazing behaviour changes with parasite infection, suggesting that sheep are able to detect metabolic signals caused by parasitism, and according to these signals start selecting plants with higher nutritional values (Cosgrove and Niezen, 2000).

Engel (2002) approached this subject by exploring behaviours of wild animals and how they manage internal parasites. It was shown that most animals have a very good understanding of what is wrong with them and often know and use the appropriate medical plants. To some extent this instinctive knowledge is still present in domesticated animals; research with goats and tanniferous plants has shown that if goats are given a choice they will select diets with moderate tannin levels.

The above discussed studies once more document how complex the relation between grazing animals and internal parasites is. It appears logical that keeping animals at the upper limit of pasture productivity interferes with the inherent necessity of ruminants to graze further away from faeces and therefore a decreased stocking rate may help to control nematodes in sheep and goats.

5.4 Monitoring and Intervention

The principle of Monitoring and Intervention builds part of the base for organic farming, particularly because, as shown in chapter two, the preventive use of any conventional treatment is prohibited. Therefore regular intensive monitoring is inevitable to guarantee animal welfare (Thamsborg et al., 2004) and protect animals against unnecessary suffering.

Because any preventive use of anthelmintics is outside the organic standards, the treatment method applied at the moment is the strategic usage of anthelmintics, where only individuals are treated (Waller, 2005). However, before any therapy can be administered it has to be established which animals are physically affected by parasitic nematodes.

There are three commonly applied methods to determine worm infestation with different explanatory powers:

(1) scoring general body condition

(2) determine faecal egg count (FEC)

(3) scoring for deviate physical conditions

The body condition should be monitored not only for signs of nematode infestation but also other negative influences. Early practice in Australia showed good results for worm control treating only a small percentage of the flock (10-20%), those animals with the highest FEC and those with the lowest weight gain. Nevertheless, treating animals with low weight gain seems risky as weight loss or limited weight gain can be due to several other conditions not necessarily due to parasitic nematodes (Waller, 2005).

The determination of faecal egg counts appears very useful in obtaining a clear picture of worm infestation within single animals as well as within a mob (mob counts) (Thamsborg et al., 2004). When the FEC reaches a specified limit (e.g. over 400 eggs/gram (EPG) in lambs) it indicates the need for treatment (Younie et al., 2004). However, a further source (http://www.ceresfarm.co.nz/internalparasites.htm) on this matter estimates trigger levels to be the following: below 500 EPG is low, in between 600 and 2000 EPG stands for moderate infestation and above 2000 EPG is critical. Consequently body condition scoring as well as faecal egg count determination allow treatment to be carried out on selected animals and therefore minimizes the risk of the buildup of anthelmintic resistance within the flock.

An approach that is quite similar to the above-mentioned faecal screening, is the use of the FAMACHA© chart to determine the degree of haemonchosis in sheep and goats (Koopmann and Epe, 2006). This chart gives farmers the possibility to assess the clinical condition by the colour of the eye mucosa (score 1-5) and drench only those animals that have a score above 3 (Bath et a., 2001). If animals become heavily infected and there is a requirement for chemical intervention, there are some points that need to be considered before the administration of any conventional de-wormer (Humann-Ziehank and Ganter, 2005):

- never treat the whole flock, only treat infected animals
- always confirm infestation by laboratory examination of a faecal sample
- check for resistance before deciding on a particular remedy
- administer treatment on empty stomach to increase efficiency
- avoid inappropriate dosing
- do not move immediately animals after drenching, wait for 1-2 days
- check success 7-10 days after drenching by laboratory FEC

6 Improvement of animal resistance through selective breeding

A further possibility of controlling parasitic nematodes in sheep and goats lies within the breeding management. The idea is to use only those animals for breeding that shows either an inherently occurring resistance or resilience to nematode challenges (Bishop et al., 1996). This idea has, as other alternative strategies, come into the fore since the extent of the spreading anthelmintic resistance of parasites has become more and more obvious.

Research that has been done in the last decades could successfully show “that it is possible to exploit genetic variation in resistance to nematode parasites of sheep by selection” (Gray, 1997). The selection for resistant animals is possible within different animals as well as within different breeds of sheep and goats (SAC, Stapledon Report, 2000). Various studies have been done on this issue, some focused on the varying degrees of resistance amongst differing breeds (Baker et al., 2004; Amarante et al., 2004), and others focused on the occurrence of resistance and its heritability within one breed (Bisset et al., 1996; Bouix et al., 1998; Gauly and Erhardt, 2001).

The outcome of these studies confirmed that within and amongst populations of animals that are challenged by internal parasites there are always animals that perform better than others, they are either resistant, resilient or tolerant (explanation see glossary)(Bishop and Stear, 2003). Breeding in recent years has concentrated on resistance last but not least because resilience is far less heritable then resistance (Eady et al., 2006). Tolerance on the other hand is not a desirable trait at all because tolerant perform well indeed but contribute to pasture contamination (Meat New Zealand, 1999).

6.1 Possibilities for Estimating Breeding Value

The starting point of science was to explore the ways of nematode transmission and how transmission could be restricted by modifying animals (Bishop and Stear, 2003). This led to the question of how resistance in animals could be measured to determine the criteria for which animals were being selected.

All studies that have been reviewed for this paper estimated breeding value on the base of faecal egg counts, however there are other methods which can also be used like the use of genetic markers and blood immunity response tests (Gray, 1997). In this context dag scores (DS) and faecal consistency scores have been looked into as possible indirect indicator traits for resistance but correlation between FEC and these traits has not been explored in full detail and results remain contradicting (Pollot et al., 2004)

In recent years most selection has been done on the basis of faecal egg counts (Bishop and Stear, 2003) but there is an additional blood screening test that has been developed to assist selection that is called the 'Host Resistance Test' (HRT) (AGresearch, 2004). This test measures the host antibody level and makes it thereby possible to select for animals with relatively high levels (AgVax, 2006).

In New Zealand, one of the leading countries in selective breeding, a selection index has been developed to give farmers the chance to select for resistance as well as production traits (Meat New Zealand, 1999). Those farmers that have been using this index for over ten years show a significant reduction in FEC, improved wool production and higher growth rates in ewes and lambs on their farms (SAC, Stapledon Report, 2000).

6.2 Relation of Resistance to other Traits

Sheep and goats have been bred for many centuries in differing and sometimes contrasting environments for various reasons, parasite resistance normally not being in the foreground. Today there is a variety of breeds - from milk to meat to dual purpose breeds either high-performing or extensive, a wide range of sheep and goats has been bred. Since the beginning of breeding towards enhanced animal resistance its relation to other performance traits (like e.g. fleece weight, body weight, fibre diameter, milk production) has been discussed and studied (Bishop and Stear, 2003). The results of the existing sources are contradicting and range from no marked genetic relationship between FEC and production traits (Eady et al., 2006), to small unfavorable genetic relationship between fleece weight and FEC (Meat New Zealand, 1999), to a significant negative correlation between FEC and daily weight gain (Gauly and Erhardt, 2001). The complex correlation of these different traits can possibly be cleared by taking a look at the underlying physiological processes (Bishop and Stear, 2003).

Animals that get challenged by nematode parasites need a surplus of energy either for an immune response or to maintain performance (e.g. growth, pregnancy, and lactation), therefore resistance and performance competes for resources, particularly for protein. These findings are confirmed by a study of Kahn et al. (2003) in which is shown that supplementation of ewes during the peri-parturient period enhances their ability to resist infection and consequently reduces faecal egg output overall in those animals previously selected for nematode resistance. The study also confirmed lower fleece weights and wool growth rates for resistant ewes and lower birth-weights for their lambs. This once more shows the physiological problem of pregnant and lactating ewes and does. Under normal conditions nematode infection would have little impact on the animal, however during pregnancy or lactation, body resources have to be divided and in more resistant animals the division turns out to be in favour of immunity (Bishop and Stear, 2003). A similar process applies for wool growth, in which case the two traits are competing for scarce sulphur containing amino acids.

So all in all these studies show that the relation in between resistance and performance traits "are a balance of the costs of being resistant versus the beneficial consequences of being resistant" (Bishop and Stears, 2003).

7 Enhancing host resilience and resistance through nutrition

The following section will concentrate on the interrelation between the nutritional status and parasite infestation in sheep and goats. This issue has been, more or less, intensively researched for about a decade now and still holds a few open questions.

The fact that the gastro-intestinal tract builds the base for a lot of physiological processes, and that it is at the same time, the central location for all those parasites this paper focuses on, makes this section particularly interesting.

The whole subject can be considered from two different points of view, the first how parasites affect the physiological processes of their hosts, and the second, how the nutritional status of the hosts can be influenced in order to enhance their resilience and resistance (Coop and Holmes, 1996).

In general it can be claimed that well nourished animals cope better and overcome infection with parasitic nematodes quicker then malnourished ones (Wells, 1999). The groups that are most susceptible to parasitism are young lambs and kids (when immunity has not been established yet) and their mothers (because of the peri-parturient drop of their immune system) (Waller and Thamsborg, 2004). Protein availability in particular (Van Houtert et al., 1995ab, Valderrábano et al., 2002) and balanced mineral supply (Sykes and Coop, 2001) seem to play key-roles in the protection from nematode infections.

As already discussed in the last section do Coop and Holmes (1996) as well as Bishop and Stears (2003) support the thesis that an animal has only a certain amount of nutritional resources (particularly protein) that have to be allocated amongst the different body functions. If the protein supply for example does not cover the necessary requirements, certain functions will be prioritized (usually to the disadvantage of immunity).

In this context the role of dietary protein has been researched intensively. Van Houtert et al. (1995a, 1995b) showed in their studies that the administration of protein supplement reduced production losses, enhanced expulsion, reduced the need for drenching significantly, increased wool production and fibre diameter and reduced faecal egg counts.

More recent studies have carried out investigations into the impact of different forage types on the performance of parasitized sheep. These studies showed a correlation between administered forages and ability to cope with worm infestation. The reviewed feeding trials both showed the positive effects on lambs feed with white clover. Niezen et al. (2002c) discovered that an increased proportion of white clover in the diet of lambs resulted in improved weight gain and overall better performance. These findings are confirmed by Marley et al. (2005) who researched the effects of forage legumes in comparison to ryegrass in lambs, moreover they showed that the consumption of white clover leads to lower FEC and a reduced adult worm burden.

Coop and Holmes (1996) reviewed studies on the influence of nutrition on (1) parasite establishment, (2) established infections and (3) immune responses. In their conclusion protein supplementation appears to have no influence on the initial parasite establishment but on established infection and the immune response which is indicated by a reduced FEC and worm burdens and by enhanced resistance to re-infection.

Valderábano et al. (2002) could not confirm a reduction in faecal egg counts in their study but it was observed that female worm size and fecundity decreased significantly with the level of nutrition. A further review comments on what other studies have demonstrated "that protein supplementation of ewes around lambing may limit the peri-parturient rise in faecal egg counts depending on protein level during pregnancy" (Thamsborg, 2001a).

Kahn et al. (2003) showed in their study that supplementation did not affect faecal egg output in the phase prior to birth but it reduced FEC by more than 50% postpartum.

The latest study that was reviewed for this paper assessed the rate of immunity improvement in lactating ewes when the demand for protein was either decreased or fulfilled (Houdijk et al., 2006). This study points out that optimized host protein nutrition could be able to reduce the establishment of parasites around the peri-parturient loss of immunity. Further more the experiment showed that the decrease in protein demand is able to induce the regain of immunity in ewes within short periods of time. The authors conclude that if the decrease in demand is able to lead to such a dramatic improvement of immunity, the optimization of nutrition might result in an equally quick improvement.

8 Nematode control through bioactive forages

In this chapter the influence of nutrition on resistance and resilience was shown and the next passage will focus on the possibilities and limitations of parasite control through feeding or grazing forages that contain anti-parasitic compounds, or nutraceuticals. Both terms refer to crops that contain plant secondary metabolites that are considered to be beneficial for the animal health rather than having an optimized nutritional value (Waller and Thamsborg, 2004).

In this context a certain group of secondary plant components, the condensed tannins have been investigated. Condensed tannins (CT) are not only included in certain plants, a lot of plants have CT content but only those with higher levels are referred to as 'bioactive forage'. As opposed to the application of medical plants, these forages are generally non-toxic and can consequently not be overdosed and the idea is to integrate them into the normal diet of ruminants (Thamsborg, 2001a).

There seem to be several options for feeding tanniferous plants. An example of this is the cultivation of arable crops that can be integrated in the normal rotation (Niezen et al., 1998), these can then be used for either de-worming paddocks, or the plants can be preserved and fed as hay or silage at a later date.

Feeding bioactive forages is not only associated with positive effects but also with some negative consequences (Coop and Kyriazakis, 2001) and this may be the reason why plants with high tanniferous content have not been used earlier. High concentration of CT is known to lead to reduced feed digestibility, feed intake and consequently lower productivity (Aerts et al., 1999; Dawson et al., 1999). Coop and Kyriazakis (2001) therefore conclude that the intake of tanniferous plants will only be preferred by grazing small ruminants "if the negative consequences are offset by the positive effects attributed to their anti-parasitic properties".

8.1 Mode of Action of Condensed Tannins

Many studies have been undertaken to find out more about the anthelmintic effects of condensed tannins, with two main explanations for the mode of action of condensed tannins being observed (Heckendorn, 2005).

- First theory: Indirect mode of action: When tannin-rich forages are consumed, the then released condensed tannins build complexes with proteins and protect these from ruminal degradation (tannins have a higher affinity to proteins then to other substances). These complexes dissociate in the abomasum and release protein, ready for absorption. Since nematode parasitism leads to a loss of protein and decreased protein absorption, the intake of tanniferous forages may balance the protein loss and thereby increase resilience. (Min et al., 2003 ; Heckendorn, 2005)
- Second Theory: Direct mode of action: Condensed tannins directly react with the proteins on the surface of the parasites and disturb the normal physiological functions of the nematodes like mobility, food absorption or reproduction (Heckendorn, 2005)

For the successful performance a certain CT-content (35 g/ day) of the applied plants seems to be necessary (Athanasiadou et al., 2005). Alternatively Min and Hart (2003) suggest that beneficial effects of CT in plants only occur within the concentration range of 45 to 55 g of CT/kg of DryMatter (DM), levels below and above this range lead to inconsistency.

There is evidence that results obtained in studies with sheep can be transferred to the application on goats (Paolini et al. 2003c/2005b). Hoste et al. (2005b) state that data obtained in goat experiments is in agreement with those in sheep. Basic physiological processes are alike indeed but it should be kept in mind that goats are more susceptible than sheep and they take longer to acquire immunity (Thamsborg et al, 2004).

8.2 Promising Plant Species

A number of plants have been investigated in the last years and it was found that the CT-content of most grasses is under 1%, most temperate forage legumes have about 5% and some tropical plants contain up to 40% (Thamsborg, 2001a).

8.2.1 Chicory

Chicorium intybus (Family: Asteraceae)

Chicory is a bushy perennial herb that has light blue to lavender coloured flowers, which is originated in the Mediterranean climate. Forage chicory is known to improve the live weight gain in lambs and to lead to lower pasture contamination because "larval survival on chicory is lower then on grasses" (Rattray, 2003). Similar results were achieved by Marley et al. (2003a, 2003b), who found that infected lambs grazing chicory had the highest live weight gain and the scanned faeces had a tendency of fewer larval development.

Anthanasiadou et al. (2005) proved strong anthelmintic activity in their in vitro studies within the scope of the WORMCOPS project. In this study extract from rumen material of sheep that previously grazed pure stands of chicory was analysed, former studies had tested extracts of plant material. The subsequent in vivo study on chicory showed that feeding chicory was indeed effective against adult *T. circumcincta* but not on incoming larvae.

These results were confirmed by a five week grazing trial (Marley et al., 2003a) and two recent studies that investigated that short-term of grazing chicory leads to a reduced adult worm burden but no differences in egg output (Athanasiadou et al., 2005; Tzamaloukas et al., 2005).

These experiments provide evidence for the ability of chicory to reduce the adult worm burden in infected sheep but they also prove the incapacity of chicory to reduce faecal egg output and prevent incoming larvae from settling. Consequently grazing chicory may help infected animals to balance weight loss due to parasitic infestation and thereby enhance the buildup of immunity. It certainly neither appears suitable to decrease pasture infectivity nor does it show the ability to protect sheep from further infestation.

Unfortunately no reports were found regarding the effectiveness of chicory on goats, so no secured conclusion can be drawn and no recommendation given in this area.

8.2.2 Birdsfoot Trefoil

Lotus corniculatus, L. penduculatus (Family: Fabaceae)

These two lotus species are herbaceous perennial legumes with yellow flowers that are native to Europe and parts of Asia (Lolicato, 1998). Lotus penduculatus is referred to as 'Greater Birdsfoot Trefoil', 'Maku Lotus or 'Greater Lotus' whereas the other species is either called 'Birdsfoot Trefoil' or 'Goldie Lotus'.

Rattray (2003) reviewed quite a few of studies on lotus that had been conducted up until 2001. Positive results were found for performance and live weight gain during infections and variable results for the reduction of egg output and worm burdens.

The results of Marley et al. (2003ab) lead to opposing conclusions. In the feeding trial (2003a) with lambs carrying mixed infections, they found that the lotus fed group had the lowest weight gain and overall showed no significant positive effect. The impact of different forages on development and survival were explored in their other study (2003b) and resulted in no effect on hatchability but the highest larval development (L_3) on birdsfoot trefoil. Two short-term grazing studies had similar results were no direct effects of birdsfoot trefoil could be investigated, although both authors wondered whether the lack of effect might have been due to a minor dosage (Anthanasiadou et al., 2005; Tzamaloukas et al., 2005).

Greater birdsfoot trefoil has also been investigated by Athanasiadou et al. (2005b) within the scope of the wormcops project but the in vitro experiments could not demonstrate any anthelmintic properties. But the in vivo trials measured a substantially declined egg excretion for *T. cirumcincta* and *Trichostrongylus spp*.

These results were less clear then those for chicory. Marley et al. (2003a) suggest that inconsistent findings could be related to the fact that different cultivars have varying CT contents. Athanasiadou et al. (2005) and Tzamaloukas et al. (2005) both wonder whether their dosage had been insufficient. Unfortunately no other study has been conducted with different cultivars and levels of CT, to either confirm, or disprove this explanation.

Judging the current stage of experiments, no recommendation for the application in practise can be given; results are inconsistent and controversial and indicate an exploratory need to finally determine the potential of birdfoot trefoil species.

8.2.3 Sulla

Hedysarum coronarium (Family: Fabaceae)

Sulla is a biennial or short-lived perennial with flowers that can vary from pink to violet originating from the Western Mediterranean and Northern Africa (Frame, 2006).

Niezen et al. (1998) found in their six week grazing trial that lambs that had grazed Sulla, had a lower FEC, reduced worm burdens and intestinal parasite density, had good live weight gain, despite infection, and were less affected by parasites.

Molan et al. (2000a) tested the effects of Sulla extract on larval development and found that the genus *T. colubriformis* was more resistant to the inhibitory effects than the other tested species. Further in vitro tests were undertaken within the scope of the Wormcops project by Hoste et al. (2005b) who observed a reduced in vitro egg hatchability but no difference in larval development. The subsequent in vivo study on lambs infected with *H. contortus* grazing Sulla showed reduced FEC and worm burdens.

Similar results were obtained by Niezen et al. (2002) who discovered that the consumption of Sulla reduced faecal egg output substantially but it also accumulated further evidence for the inefficiency of Sulla on *T. colubriformis*.

The short-term feeding trials of Athanasiadou et al. (2005), Tzamaloukas et al. (2005) and Pomroy and Adlington (2006) do not support any of the previous evidence, both trials show no positive results for Sulla consumption. The former two studies both argue that the lack of effect could be due to insufficient levels of CT, Pomroy and Adlington state similar level of CT in their diet like Niezen et al. (2002) and conclude that the lack of effect must have another reason.

The presented research results indicate that there is a discrepancy between longer and short-term experiments. The administration of Sulla seems to have no effect when applied for a short period of time but if fed for longer, it may reduce FEC and have a positive effect on animal performance.

A further question that should be considered is if it is possible to integrate the cultivation of Sulla into the farming routine. Pomroy and Adlington state that “Sulla is a difficult herbage to manage agronomically” and they further quote that the provision of a substantial amount of Sulla for an extended period of time for all animals on a farm seems difficult to achieve. Information about Sulla in the FAO-database indicates that weeds can affect Sulla at establishment, as well as after cutting, and that it is not suitable for intensive grazing (Frame, 2006).

These aspects need to be considered and indication is given that further research is necessary to find out more about the cultivation attributes of Sulla, particularly for organic agricultural systems. Moreover it seems advisable to establish the period of time required for the successful reduction of FEC.

8.2.4 Sainfoin

Onobrychis viciifolia (Family: Fabaceae)

Sainfoin is a perennial herb which is distributed in Europe, parts of Asia and Northern America (Frame, 2006).

Barreau et al. (2005) showed in their in vitro experiments the activity of Sainfoin extract against *H. contortus* nematodes and therefore confirmed the results of Paolini et al. (2004) who had demonstrated the inhibitory effect of Sainfoin extracts on L_3 of *H. contortus* and *T. colubriformis* and on adult *T. circumcincta*.

Positive in vivo results have been shown in several studies. Thamsborg et al. (2001) observed in an in vivo study normal growth rates for lambs on Sainfoin, a more than 50% reduced faecal egg output of infected animals and the tendency of lower establishment of incoming larvae and expulsion of adult worm burdens. Recently there have been many studies on the possible effect of Sainfoin with all confirming the significant reduction of FEC after the consumption of Sainfoin (Paolini et al., 2003c; Thamsborg et al., 2003; Athanasiadou et al., 2005b; Hoste et al., 2005a; Lüscher et al., 2005; Paolini et al., 2005b).

There were two short-term trials conducted on the effect of Sainfoin consumption on establishment of incoming larvae in which no evidence for any significant effects could be found (Athanasiadou et al., 2005; Paolini et al., 2005a). These findings are supported by Thamsborg et al. (2003) who showed that the consumption of Sainfoin previous to infection did not influence establishment. The only study on Sainfoin without any significant effects remains the one of Athanasiadou et al. (2005) but they cite that the concentration of CT in the Sainfoin swards might have been insufficient.

The reviewed research results provide evidence that the administration of Sainfoin can reduce faecal egg count and therefore lead to lower pasture contamination. Lüscher et al. (2005) continue to research the potential for the practical integration of tanniferous plants into agricultural practise in their large-scale project and argue that first results in particular on Sainfoin show that this plant has promising potential. In fact not all studies display the same optimism when it comes to the cultivation of Sainfoin, Thamsborg (2001b) states that Sainfoin appears not competitive in leys and has high weed infestation and Athanasiadou et al. (2005b) also mention poor establishment of Sainfoin.

Frame (2006) writes in about Sainfoin that “monocultures lack competitiveness to weed invasion” when compared to cultivation of mixed Sainfoin/grass stands.

This indicates the need for further research particularly on the cultivation side of feasibility. No recommendation can be given as long as it is not clear how suitable Sainfoin is for different climates and especially for the non chemical methods of organic agriculture.

8.2.5 Quebracho

Schinopsis ssp. (Family: Anacardiaceae)

Quebracho is the Spanish name for a group of similar species of trees that are originated in tropical South America (Wikipedia, 2006). In the medical context Quebracho is referred to as an extraction from the bark of one the Schinopsis ssp. which is rich in condensed tannins (Paolini et al., 2003a).

The first study to be considered in this context in an extensive long-term (10 weeks) feeding study on sheep by Athanasiadou et al. (2000) with several interesting results: the administration of quebracho led to a reduction in FEC and later to lower female fecundity and adult worm burden, however the observed differences were not always significant. During the trial it was also noticed that the animals receiving quebracho had a lower live weight gain and inferior food conversion, although performance of parasitized animals did not decline to the same extent as control animals.

Two short-term experiments were conducted by Paolini et al. (2003ab); in these experiments previously infected goats were drenched with quebracho extract on a daily basis for 8 days. One group was infected with *T. colubriformis* and *T. circumcincta* (2003a) and the other group was infected with *H. contortus*. In all groups the treatment led to a reduction in egg excretion and female fecundity, with no change in the established adult worm population. This study also tested the effect of quebracho on incoming larvae of both species and a reduction was only observed for *T. colubriformis*, the reduction of *T. circumcincta* larvae was insignificant.

The following conclusions can be drawn from the above experimentation: the administration of quebracho extract appears to lead to a reduction of egg excretion and female parasite fecundity but it does not seem to lower the adult worm burden. There are no verified results available on effect of incoming larvae. However studies on quebracho administration remain scarce and although the available results are relatively clear and indicate anthelmintic properties for quebracho, more studies are required to confirm the existing results.

A further critical point that needs to be proved is the availability of quebrancho extract, which is certainly also a question of costs. It needs to be estimated whether farms can afford to purchase the delivery of this extract, or whether the application of quebracho will be limited to areas where *Schinopsis ssp*. are naturally grown.

8.2.6 Other Species with high Tanniferous Contents

Apart from the above described plants, a range of grasses, shrubs and bushes have been chemically analysed for their CT-content and anthelmintic activity in vitro. Some have shown promising results when tested in vivo however not with the same benefits shown as the previously examined plants.

The following list shows tanniferous plants that have been the item of scientific consideration, either in in vitro, or in vivo studies, or both. The list is not exhaustive with research in this field an ongoing process.

Table 5. Effect of different plants/herbs on endoparasite (in vivo and in vitro)

Scientific name	Traditional name	Studies
Forage plants		
Dorycnium pentaphyllum	Socarillo	Molan et al., 2000b ; Niezen et al., 2002b
Dorycnium rectum	No common name	Molan et al., 2000b, Niezen et al., 2002b; Waghorn et al., 2006
Lespedeza cuneata	Chinese Lespedeza	Min and Hart, 2003; Min et al., 2005
Rumex obtusifolius	Dock	Molan et al, 2000b; Thamsborg, 2001a
Shrubs and Trees		
Acacia karoo	Wattle (leaves)	Kahiya et al., 2003
Calluna vulgaris	Heather	Hoste et al., 2005b
Castanea sativa	Chestnut Tree (fruit)	Hoste et al., 2005b
Cornus sanguinea	Common Dogwood	Athanasiadou et al., 2005b
Corylus avellana	Hazel tree	Paolini et al., 2004
Erica ssp.	Erica	Athanasiadou et al., 2005b
Pinus sylvestris	Pine tree (leaves)	Hoste et al., 2005b
Punica granatum	Pomegranate	Athanasiadou et al., 2005b
Quercus ssp.	Oak	Paolini et al., 2004; Hoste et al., 2005b; Athanasiadou et al., 2005b
Robinia pseudacacia	Black Locust	Athanasiadou et al., 2005b
Rubus fructicosus	Blackberry bush	Paolini et al., 2004; Hoste et al., 2005b
Salix ssp.	Willow	Barry et al., 2005; Diaz-Lira et al., 2005
Sarothamnus scoparius	Genista (leaves)	Hoste et al., 2005b
Vitis ssp. extract	Grape Seed extract	Waghorn et al, 2006

Shrubs and trees are of particular interest because of the alimentary spectrum of sheep and goats and their ability to browse a wide range of plants. In this context the nutritional consequences of goats browsing rangeland environments has been extensively studied, but it has taken longer to focus research on the correlation between browsed plant species and parasite infection status. Despite the scarcity of studies there is evidence of a positive effect on parasitism (Hoste et al., 2001; Hoste et al., 2005c). Although sheep are generally categorized as grazers, they still browse trees and shrubs to some extent and as current research results from New Zealand indicate this can have beneficial effects on the resilience to parasitic nematodes (Diaz Lira et al., 2005).

9 Alternative anthelmintic treatments

The last chapters dealt with non-chemical strategies to control internal parasites in sheep and goats, with these introduced non-chemical approaches form the framework for the animal health and welfare regarding parasites. However none of these non-chemical options offer immediate help for infected animals, they cannot be ordered or bought in a shop, they involve longer planning and require basic epidemiological knowledge. The following chapter will deal with the chemical side of parasite control on the basis of alternative treatment either derived from plants, plant mixtures or by means of homeopathic remedies.

9.1 Copper-Oxide Wire Particles

The basic principal of this treatment is that the availability of macro-minerals and trace elements influences the host-parasite relationship (Suttle and Jones, 1989 in: Chartier et al., 2000). When copper-oxide wire particles (COWP) are administered they remain in the rumen and release free copper into the abomasum which creates an environment that affects *H. contortus* ability to remain established (Burke et al., 2004).

Bang et al. (1990) found that the administration of copper-oxide wire particles led to a good reduction of parasite burden of *H. contortus* but the impact on other species was very average. Further research proved the efficiency of (COWP) on *H. contortus* in goats but also showed that it does not influence greatly on other species (Chartier et al., 2000).

Other research come to similar conclusions, the treatment seems to successfully reduce FEC and the number of established adults of *H. contortus* but does not work effectively on other species (Watkins, 2003). Burke et al. (2004) evaluated to optimal dosage for administration and found 2g as a single dose to be sufficient to result in reduced FEC and worm burden but not enough to lead to toxicity or predispose lambs to disease which higher concentrations do.

9.2 Homeopathy

Homeopathy will not be discussed in detail for two reasons. The first is that the last paper that has been written about alternative helminths control a year ago has already dealt with homeopathy sufficiently and the report on homeopathy can be recommended (Häublein, 2005). The second reason is that according to the findings of the last paper homeopathy is considered unsuitable to treat acute helminthosis in most cases. This is due to several circumstances, amongst them the lack of veterinarians that have an additional homeopathic qualification and that the application of homeopathics requires detailed knowledge as incorrect dosing rates can lead to overreaction and worsen the condition.

Despite the above findings it still cannot be generally claimed that it is impossible to de-worm with homeopathic remedies, good results have been obtained in the past in independent reports (Gibbons, 2002).

The mode of action of homeopathy is based on a thorough anamnesis and on the provision of adequate animal husbandry. It requires time and the will of the farmer to think over the whole farming process in order to detect the source of susceptibility.

In conclusion, it can be ascertained that homeopathy has the potential to help the animal to overcome its deteriorating condition caused by parasitic infection but it is currently considered unsuitable as a short-term measure to treat intestinal nematodes on organic farms (Cabaret et al., 2002b; Humann-Ziehank and Ganter, 2005).

9.3 Phytotherapeutical Measures against Internal Parasites

Phytotherapy is either prophylactical or therapeutical use of plants, their plant components or their preparations, and can be divided into allopathic and traditional phytotherapy (Hördegen, 2005). The allopathic phytotherapeutical approach uses scientific testing to verify the anthelmintic effectiveness of a plant or preparation, and in contrast to that the use of traditional products is based on handed down knowledge (Anonymous, 2005 in: Hördegen, 2005).

The evaluation was focused on possible risks and side-effects of plants, and on scientific verification. Listed are herbs and preparations that have either proved to have an anthelmintic efficacy (scientifically tested) or that are traditionally associated to help against internal parasites. The criterion for inclusion into the table was the frequency in which plants were mentioned in coherence with anthelmintic activity. It is important to keep in mind when considering alternative options in this area that there still remain a lot of plants not evaluated. Of the plants that have been evaluated who have been only a small number have been scientifically tested and an even smaller number have been tested in a veterinary-medically context.

9.3.1 The Applicability of Phytotherapy

At the current stage veterinarians that are willing to work with phytotherapy have to deal with two basic problems. First of all effective plants have to be divided from ineffective ones, and secondly the physiological consequences of herbal administration need to be determine, including possible risks and side-effects. Preparations derived from plants are often thought to be harmless and widely associated to have fewer side effects and are therefore considered easier to apply, however reality shows that plants and plant extracts can be as toxic as allopathics, that they can have side effects, and if applied inappropriately they can cause severe damage and even lead to death (Reichling and Saller, 2001).

A further problem that has been explained and discussed by Häublein (2005) is the legal requirements for the use of homeopathical and phytotherapeutical remedies in the EU. These remain restrictive and discouraging for both veterinarians and farmers, with no change in the foreseeable future. For further information on this matter refer to Häublein (2005).

So before advising or suggesting anything to practically working people, these aspects should be well thought of.

9.3.2 Historical Context and Future Outlook

From the scientific point view little has been done in this area, even though a lot of plants are currently used in third world countries. These countries either have no need for modern medicine, because they rely on traditional knowledge or their access to modern veterinary anthelmintics is very limited because of their location and their financial situation (Hördegen, 2005). In countries where veterinarians are rare and expensive, and the single animals often has a higher esteem, great demands are placed on farmers. They are not only dealing with helminth infections but also have to be able to treat a whole range of other diseases with often successful outcomes (Nfi et al., 2001).

Sheep and goat farmers can be divided into two categories, the ones that are able to afford modern veterinary products, and the ones that cannot. Farmers that have access and can afford veterinary drugs have managed nematodes through the use of chemistry, with the second group, those without access or the financial means, continuing to use traditional remedies with more or less success.

Due to the increasing problems with modern veterinary products and the increased effort of research to find alternatives, traditionally administered plants and plant preparations have become interesting again. This has triggered the evaluation of some of these traditionally applied plants for their anthelmintic properties with a view to finding out more about them.

The problem science has to deal with at this stage is the huge variety of plants that may or may not be suitable for the development of alternative anthelmintics. There is also the current lack of verified information to contend with. For these reasons effective plants need to be divided from ineffective ones and the quickest means of achieving this is with in vitro methods. Once a plant has proven its efficiency in vitro, further in vivo testing will be necessary to confirm the obtained results and evaluate risks, side-effects and future applicability (Hounzangebe-Adote et al., 2005a). At this stage it seems a long way off from the discovery of a potential plant to the release of a commercially viable product for use on farms.

In conclusion future research in this area seems promising, there remain a lot of plants to be tested but it is possible that there are some plants that possess a high anthelmintic effectiveness and cause no side-effects.

In the retrospection of the literature research it has been concerning to discover the incomplete and possible misleading information that is available on the internet and in other sources. The information published by Duval (1994) and the University of Aberdeen is possibly well meant but it can not be considered sufficient to only occasionally and briefly mention possible risks of plants and their preparations. This information may be misinterpreted, with people applying the information in a belief that they are doing their animals a favour by not using common anthelmintics but ending up doing severe damage to their stock.

Some preparations like copper sulphate should actually not even be mentioned as an alternative treatment. So one needs to be very careful before giving any advice to practically working farmers and only introduce plants and preparations with reference to risks and side-effects.

Table 6. Plants and plant preparations used as alternative anthelmintics

Botanical & Common Name	Preparation	Dosage	Risks, Side-effects & Effectiveness	Scientific Verification & Comment	Prime Source
Allium sativum Garlic	Crushed cloves	1 Tsp/ animal/day	No side-effects known, further investigation of effects on derogation of milk-flavour, Effective against GIN and lungworms	traditionally applied In vivo trial showed no effect of garlic administration contradicting statements of the effectiveness	Allen, 1998 Duval, 1994 Cabaret et al., 2002b Meat New Zealand, 1998 Perezgroves, no date University of Aberdeen, no date
	Dried powder	Mixed in with feed Dosage not specified			
	Juice	Oral drench Dosage not specified			
	Capsules	2-3 / animal/ day			
Annonum senegalensis Custard Tree	Dried stem bark extract	Not specified for living animals	No toxicity noted	Traditionally used by Nigerian farmers In vitro test showed promising potential	Alawa et al., 2003
Artemisia abrotanum Southern	Powdered herbs	1 Tbs/ sheep/ twice daily for several days	No toxicity noted	Although traditionally used, activity	Hoffmann, 1995 in: Häublein, 2005

Wormwood	Young flowering shoots	Not specified		seems reliable	PFAF, 2002
Artemisia absinthium Common Wormwood	Dried and crushed flowers	Used or steeped in cold water	Light to medium toxic, usage can therefore not be recommended	Reputation of anthelmintic effect in trad. medicine In vitro tests showed barley sign. reduction of Trichstrongylus	Bara et al., 1999 in: Devantier, 2004 Duval, 1994 Wikipedia, 2006
Artemisia cina Eurasian Wormwood	Floral heads and seeds	Not specified	Larger quantities of this plant are toxic and even smaller amounts cause side-effects No effect on tapeworms	It is used for the fabrication of Santonin which is used in human medicine	PFAF, 2002 Duval, 1994
Artemisia dracunculus Tarragon	Leaves and oil	It is suggested to let it grow in the paddock and let animals voluntarily consume it	Not to apply in pregnant animals	Is known to have vermifuge properties in the traditional medicine	Duval, 1994 PFAF, 2002
Artemisia herba-alba	Powdered shoots	10-30 g / animal	No information available	Powder was used in a trial with goats infected with *H. contortus* and worked successfully	Idris et al., 1982
Artemisia vulgaris Common Mugwort	Dried and crushed flowers	Not specified	Slightly toxic, not to be used in pregnant animals	No reliable source could be found that confirms the unobjectionable efficacy	Duval, 1994 PFAF, 2002 Wikipedia, 2006 www.feenkraut.de
	Infusion	4 tsp/ l, steep for 1-2 minutes			
	All parts of the plants	Not specified			
Asarum canadense Wild Ginger, Snakeroot	Dried roots	Not specified	Leaves are toxic	Is known to work as an anthelmintic, traditionally used in Africa, no conducted trial could be found	Duval, 1994 PFAF, 2002
Azadiracta indica Neem tree	Seed and kernel oil Dried leaves Fruit Seed cake Bark	Doses depend on administration form	Latest in vivo trials give no indication of efficacy, one even found that consumption leads to increased FEC	Results are scientifically verified but vary	Costa et al., 2006 Githiori, 2004 Thomas et al., no date www.neem-foundation.org
Carica papaya Papaya	Latex/ Seeds/Leaves Fruits/ Roots all contain act. compon.	Administration according to active component content	Decreasing fertility Might cause abortions shortly after conception	In vitro trials have confirmed anthelmintic activity Used	Animal Science at Cornell University, 2001 Hoste et al., 2005d

	Watery mix of leaves and fruit	350ml for calves, for sheep and goats equivalently fewer	No other adverse effects	traditionally in the Philippines and other countries In vivo trials with papaya seeds in sheep showed 80% reduction in FEC In vivo trial with calves show reduction of 60%	Hounzangbe-Adote et al., 2005a Ronoredjo and Bastiaensen, no date Stepek et al., 2004
	Extract of plant material	Used in in vitro tests			
	Grounded seeds mixed with water	3g seeds/ kg/ BW for six days			
Chenopodium ambrosioides Goosefoot, Wormseed	Seeds or essential oil expressed from the seeds	Not specified	Essential oil is highly toxic in higher doses, commonly used vermifuge before availability of mod. anthelmintics Less effective against tapeworm Usage not recommended	Internet database and Cornell University seems to have investigated thoroughly	Animal Science at Cornell University, 2001 PFAF, 2002
	Oil, whole plants or the leaves grounded and mixed with water	Goats: 0,2ml/ kg BW Sheep: 0,1ml/ kg BW			
Chrysanthemum cinerariifolium Pyrethrum	Administered in powder from	Not specified	Very low toxicity for mammals	It has been discussed for years but two in vivo trials found no and very low anth. efficacy	Duval, 1994 Hammond et al., 1997 Mbaria et al., 1998
Crucifers There are several species of the family cuciferae that are used as anthemintics	Brassica nigra and Sinapsis alba seeds	2 ounces/ lamb	Can be toxic if large quantities are consumed	All traditional plants with anthelmintical reputation, no in vivo experiments could be found	Duval, 1994 PFAF, 2002
	Brassica oleracea and Descurainia sophia seeds	Not specified			
	Raphanus sativus	Not specified			
	Armaratia rusticana Brassica rapa Nastrium officinale	Not specified	No data could be found on the activity of the species		
Curcurbita pepo Pumpkin	Seeds	60 g/ sheep in 3 doses and administered with oil to expel worms	Regarded as safe when taken appropriately no info on pregnancy and lactation available Sprouting seeds produces toxins	Activity scientifically researched, reliable sources	Anonymus, 2003+ Duval, 1994 Hoffmann, 1995 in: Häublein, 2005 PFAF, 2002

Daucus carota Wild carrot	Whole plant Root Seeds	Not specified	Root can induce uterine contraction and other side effects are suspected	Plant can not be recommended because of missing scientific verification	Duval, 1994 PFAF, 2002
Dryopteris ssp. Fern (D. filix-mas quoted the most)	Rhizomes and young shoots Ether extract Root stalks	The comprised filicin paralyses worms, treatment should instantly be followed by an non-oily purgative to remove paralysed worms	Caution all species are toxic in higher doses, drying and cooking will remove the toxic ingredient but not 100% Dosage is critical	Popular and effective against tapeworms	Cabaret et al., 2002b Duval, 1994 PFAF, 2002
Eucalyptus grandis Eucalyptus	Fresh leaves Leaves extracts	Depends on many factors	Can be toxic, it is difficult to determine toxic potential	In vivo test in goats led to 90% reduced FEC on *H. contortus* but none on Ostertagia	Animal Science at Cornell University, 2001 Bennet-Jenkins and Bryant, 1996
Ferula conocaula, F. gigantea **F. narthex** Fennel	Gum resin obtained from roots Grazing growing fennel	Grazing for approx. 20 days on F. gigantea, worms get eliminated after 2-3 days	None known	Traditionally used, no scientific tests available	Duval, 1994
Fumaria parviflora Small-flowered/ Fine-leaved Fumitory	Aqueous ethanol extract of the whole plant	183mg/ kg BW	No signs of toxicity in in vivo trials yet	Extract had the same efficiency as common anthelmintic control product Promising alternative	Hördegen et al., 2003 FIBL activity report, 2004
Juglans regia English Walnut Black Walnut	Leaves Oil from the seeds Bark Root	Not specified	None known	Long history of medical use Traditional anthelm. Known to expel worms	Edward, no date
Khaya senegalensis Gambian Mahagony	Ethanol extract of the powdered bark	500mg/ kg BW	None known	Traditionally used as a vermifuge In vitro and in vivo tests confirmed anthelmintic potential	Ademola et al., 2004
Mallotus philippensis Kamala Tree	Powdered fruit Aqueous or methanol extracts	375mg/ kg BW	Administration leads to diarrhoea and restlessness which vanishes after a few hours	Scientific trials confirmed in vitro and in vivo anthelmintic activity	Akhtar and Ahmad, 1992 Singh et al., 2004

Melia azedarach Chinaberry Tree Indian Lilac	Leaves Bark of the roots Pulp of the fruit	Not specified	The fruit is a little poisonous, green fruit more than ripe Active against *H. contortus* and other species	Trial with goats was successful and showed virtually no side-effects	Akhtar and Riffat, 1984 in: Hammond et al., 1997 PFAF, 2002
Melinis minutiflora (Panicum minutiflora) (Panicum melinis)	Roots are grounded and mixed with water and orally applied Crude ethanol extract for in vitro trial	Not specified /	The comprised oxalats lead to adverse nutritional effects that can be compensated if animals have time to get used to consumption	Traditionally used in the Dominican Republic as a de-wormer Cornell University did in vitro tests on *H. contortus* that indicated some effect	Animal Science at Cornell University, 2001
Newbouldia laevis Boundary Tree	Roots Leave extract	Not specified	No data available	Traditionally used by farmers in W.-Africa Confirmation of anthelm. Activity through in vitro testing	Brown, 1992 Hounzangbe-Adote et al., 2005a
Nigella sativa Black Cumin	Essential oil Ripe seeds Powdered seeds	2,5g/ kg BW	None known	Traditionally used as a anthelmintic, in vivo trial with Monezia confirm effect on tapeworms	Iqbal et al., 2005b PFAF, 2002
Ocimum sanctum Sacred Basil **Ocimum gratissimum** Basil	Leaves	Not specified	Hepatotoxic Hepatocarcinogenic In larger amounts	Confirmation of in vitro testes with *H. contortus*	Anthony et al., 2005 Asha et al., 2001 Pessoa et al., 2002
Spigelia marilandica Pinkroot Indian Pink	All parts of the plant can be used Root in particular	Not specified	Safe when used in proper dosage Poisonous when used in larger quantities	Especially effective with tape- and roundworms, treatment should always be followed by a saline aperient	University of Aberdeen, no date PFAF, 2002
Tanacetum vulgare Tansy	Seeds Leaves and flowering tops Infusion of the whole plant	Can be administered as fresh forage	Plant is poisonous if large quantities are consumed	Traditionally applied, no in vivo results available In vitro testing showed effectiveness Other species seem to possess anthelm. properties as well	Duval, 1994 Gadziev and Eminov, 1986 in : Devantier, 2004 PFAF, 2002

<table>
<tr><td>Zanthoxylum zanthoxyloides
Fagara</td><td>Freshly cut leaves</td><td>4g / kg BW for three days
500g leaves/ sheep</td><td>Not mentioned</td><td>Traditionally applied in Western Africa
In vitro tests confirmed activity
In vivo tests showed that regular feeding is better then a single cure</td><td>Hounzangbe-Adote et al., 2005a
Hounzangbe-Adote et al., 2005b</td></tr>
<tr><td colspan="6">Mixtures of Plants and other Components and Alternative De-wormers</td></tr>
<tr><td>Apple Cider vinegar infusions</td><td>Advised Plants:
Wormwood
Tansy
Pumpkin seed
Leaves and roots of the Stinging Nettle</td><td>Let one plant steep in CV for 1-3 weeks
No drench dose mentioned, can be put in water troughs</td><td>See herbs above, not drench pregnant animals</td><td rowspan="2">According to the biodyn. Health Guide cider vinegar is a good base for steeping de-worming herbs and plants in Scientific trial with commercial CV and garlic resulted in no signif. results</td><td rowspan="2">BioDynamic Health Guide, Chapter 2
Devantier, 2004</td></tr>
<tr><td>Apple Cider Vinegar (CV) infused with Garlic</td><td>1kg garlic steeped in 10-20l CV for up to 30 days; add 1l olive oil/ 10l just before drenching</td><td>drench at intervals of 2h twice with 100ml/calf so equally less per sheep or goat</td><td>Not mentioned what happens in case of overdosing</td></tr>
<tr><td>Copper Sulphate</td><td>1% solution in water treatment is applied in the morning before animals have eaten and followed by oil ½h later</td><td>50ml/ lamb
100ml/ adult sheep
animals have to be left unfed for 2 hours after treatment</td><td>Can be highly toxic</td><td>It is described as an early remedy which was relatively ineffective and often highly toxic
The other source stated a clear effect</td><td>Duval, 1994
Vlassoff and McKenna, 1994</td></tr>
<tr><td>Diatomaceous Earth</td><td>Is made from the remains of fossilised marine algae called diatoms</td><td>It is usually used as an insecticide in organic gardening
And it has been claimed that it acts as a de-wormer when fed at 2% of the daily ration</td><td>Inhalation is stated to have negative consequences on health so the fine powder needs to be applied with water</td><td>One in vivo trial could be found, which showed no de-worming effect</td><td>Allen, 1998
Duval, 1994
Wells, 1999</td></tr>
<tr><td>EcoVet</td><td>Homeopathic and herbal formulation</td><td>Administered orally following package insert</td><td>None known</td><td>Commercial product supplied by Lifespan New Zealand Ltd.
Tested with negative results</td><td>Devantier, 2004
www.lifespan.co.nz</td></tr>
</table>

Hoeggers Herbal Wormer	Wormwood Gentain Fennel Psyllium Quassia Commercial product by Hoegger Goat Supply	1,5 tsp twice daily for three consecutive days	No data available	Their web side refers to a positive research report which could not be found on the www An in vivo trial showed no effect of this powder on infected sheep	Allan, 1998 www.hoeggergoatsupply.com/info/report.shtml
Linseed Oil with Pine Tree Turpentine	Raw linseed oil Turpentine	Lambs: 10-15 drops turpentine mixed with an ounce of oil Sheep: 80 drops turpentine mixed with 2 ounces oil	Use with caution: If turpentine enters the respiratory system it may cause spasmodic closure of the mouth, therefore let the mixture be absorbed by grains before	No reliable research data could be found on this matter but it does not appear like a very safe method and can therefore not be recommended	BioDynamic Health Guide, Chapter 2 Duval, 1994
Wormaway-Sheep Wormaway-Goats	Homeopathic preparation different for each animal species	Used in individuals in tabular form or as oral drench Applied to the hole flock as described above or through the water supply	None known	Commercially supplied by a New Zealand company, their own tests verify the effectiveness; an independent study could not find an anthelm.	Animalhealth solutions Ltd. http://www.animal.co.nz/ Devantier, 2004

10 Conclusion

Parasitic nematodes remain a major threat to the health and welfare of small ruminants all over the world and the demand for alternative control measures has constantly increased during the last years. Infestation with endoparasites can have severe consequences for the animal as well as for the livestock farmers leading to economic loss and restricted productivity (Holst, 2005).

In the last decades parasites have been controlled with the preventive use of anthelmintics which has resulted in parasitic drug resistance. Although resistance in parasites is spreading, commercial farming continues to rely on the preventive use of anthelmintics.

Since the development of organic farming principles that postulate increased animal welfare and sustainability of farming methods, and the entry into force of the EU-Regulation 1804/1999 concerning veterinary treatment, the situation for many organic farms has become more and more difficult. Currently the preventive use of anthelmintics is prohibited while discovery of an equal substitute for the former used drugs does not yet appear to have been found. This process has resulted in an enforced effort from science to find effective alternative options which can be applied in organic agriculture, and also as a way of balancing the decreasing effectiveness of chemo-therapeutic measures.

Consequently the aim of this paper was to investigate the level of research in alternative strategies for control and prevention of endoparasitic diseases in organic sheep and goat farming systems, and discuss the obtained results with regard to overall viability in organic agriculture. The emphasis was put on alternative strategies for prevention because this measure aligns more with the overall principles of organic agriculture, which is to maintain health rather than curing disease.

Reviewed were the following options: biological control, pasture management, selective breeding, optimised nutrition and bioactive forages. Although a lot of research has been done on biological control options the outcome of this area of investigation proved rather disillusioning. The use of fungus spores to control infective larvae on the pasture cannot be recommended because of the high variance between results obtained under experimental conditions and those obtained in field trials.

Effective pasture management on the other hand proved promising and offers solutions that can be successfully transferred to most farming situations with applied knowledge about host-parasite interactions and interrelations building the base for low pasture infection rates for grazing animals. There are also a number of possible management strategies (e.g. stocking rate reduction and regular intensive monitoring of animal condition) that can also help optimise animal health status.

The area of selective breeding has also shown promise as a viable control option. It is currently being practised in New Zealand and Australia with good results. Animals with strong resistance to infection are being selected for future breeding lines and as a result flocks of animals with higher resistance are being produced. As yet limited research or results have been obtained under European production conditions but this is an area which warrants future investigation.

The influence of nutritional status was also investigated in the context of non-chemotherapeutical options for control. It was found that optimised nutrition improves the ability of animals to cope with the adverse effects of worm infestation. Protein nutrition proved to be playing a key role as it is needed for growing processes as well as for immune responses. Two measures can be recommended from the findings of this report. First of all farmers should ensure sufficient food supply for their stocks at all times to avoid nutritional stress. Secondly animals that are particularly susceptible can be helped by placing them on protein-rich diets.

Another interesting research area is the administration and cultivation of bioactive forages, with a number of forages displaying promising potential. Scientific research has mainly concentrated on the extracts of the plant species chicory, birdsfoot trefoil, sainfoin, sulla and quebracho. The analysis of these plants showed all plants to have some positive potential, but also highlighted individual limitations in application. Other promising plant species were briefly discussed and showed similar findings. However from the results of this literature review none of the investigated plants have been researched sufficiently in on farm experiments to recommend any for implementation at this stage.

Alternative anthelmintic treatments are covered as well: phytotherapy, copper oxide wire particles and homeopathy, with the latter two areas were proven to be of marginal interest only. Phytotherapy turned out to hold promising options, although it has undergone far less research and in the EU as there is a restrictive legal background limiting its application.

Anthelmintic plants revealed a lot of potential options and although no concrete recommendation for a single plant can be given, further research on promising species for the commercial use is strongly recommended, as is the review of the law concerning the appliance of plant based remedies.

Many scientific studies and projects have been reviewed for this paper and these have often shown big discrepancies between results obtained under in vitro and in vivo conditions. Often research is carried out under clinical conditions for extended periods before being moved to on farm trials and it was observed that extensive clinical research on a topic does not necessarily result in the discovery of a practical control option. While the difficultly of field trials is acknowledged (difficulty controlling parameters, etc.), it is important for them to be undertaken as early as possible to prove the viability of further research.

In conclusion the most viable control strategies proved to be development of sustainable farming systems, adoption of effective management strategies and phytotherapy.

- Phytotherapy showed numerous plants with strong anthelmintic properties and further research into those can strongly be recommended but that should not be the only focus.
- Organic agriculture in many cases seems to continue commercial farming methods while trying to avoid the use of all those chemicals that are required to maintain commercial systems in some kind of balance. However, the aim should be to develop sustainable farming systems that do not need either high inputs or constant damage control.
- This will only be achieved by revealing the real reasons for problem areas and finding adequate solutions for them. In terms of parasitic control this means the adoption of effective management strategies that aim at low pasture infectivity and optimised animal health.
- On many farms the realisation of bigger changes is often difficult because managers are over-taxed with finding immediate solutions for animal health problems and do not have the necessary distance to critically review their own work practises.
- On-farm consulting services that critically analyse all routines and processes, with particular emphasis on improved animal health, would provide an impartial opinion and advice in order to optimise farming practises with a view to controlling endoparasites.

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