Refugia-Based Strategies for Parasite Control in Livestock

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Key points

- Refugia-based strategies are intended to help slow the development of anthelmintic resistance by leaving a population unexposed to a treatment.
- Refugia can be supplied in several forms and through a variety of means that vary immensely in their complexity, and not all will fit with every livestock farming system.
- Three main forms of refugia-based strategies are whole flock-targeted treatment, part flock-targeted selective treatments, and selectively leaving a portion of the flock untreated.
- Incorporating refugia-based strategies into production systems typically requires a change in farm management and greater inputs, which may hinder farmer uptake.

The concept of refugia

With the emphasis on anthelmintics for worm management, “refugia” are defined primarily by the proportions of a given parasite population on pasture (mainly worm eggs and larvae) or in untreated hosts that not only escape exposure to deleterious substances,[1,2] but also contribute to the next generation thereof.[3] The concept of refugia was first described by ecologists with regard to the Last Glacial Maximum for categorizing habitats with spatial and/or temporal dimensions with potential for maintaining the viability of biota.[4] However, it was not until the need for application of the principles of refugia to the use of chemicals for management of mosquito vectors of various infective diseases was pointed out[5] that it was considered in the fields of parasitology and pests.

The expectation from the theory of effective application of refugia in gastrointestinal nematode (GIN) management is that susceptible alleles will be maintained in a population if a sufficient proportion of worms are in refugia, and that these will therefore dilute the frequency of resistant genotypes within the population[6,7] to the extent that the chances of resistant adult worms mating with other resistant adults, and thus the rate of selection of resistance is reduced.[8,9] By deduction, the general expectation is that the lower the proportions of target organisms that escape exposure to any given antiparasite/antipest substance (thus in refugia), the greater the chances and speed that the development of resistance will occur, and that nematodes in refugia would dilute the resistant genotypes within the population.[6,7]

Refugia come in many forms and can be incorporated into parasite management in a variety of ways. The sources of refugia are (1) free-living stages of helminths in the environment at the time of treatment (suprapopulation); (2) any lifecycle stage in the host which is refractory (but not resistant, eg, histiotrophic larvae) to a particular drug treatment; and (3) parasitic stages (infrapopulations) in untreated hosts.[10] Broadly speaking, 2 concepts of animal treatment regime have been proposed as means of providing refugia, being either targeted treatment (TT) in which all animals are treated based on a risk assessment of severity of parasitism[11] and targeted selective treatment (TST) where anthelmintic treatment is administered only to individuals that seem to suffer consequences of parasitism or are likely to benefit from receiving a treatment.[12, 13, 14] Alternatively, by default, this may also consist of withholding treatment from individuals that are perceived as not needing treatment, and this has been referred to as selective nontreatment. This may still be considered to be a form of TST; however, in TST we are selecting the animals to treat based on some parameter of need, whereas in selective nontreatment we simply leave a portion (eg, the best looking animals) of the herd/flock untreated. Regardless of the approach taken, the underlying basis of all of these approaches is the provision of refugia to reduce the selection pressure for the development of anthelmintic resistance by maintaining populations of nematodes that are not exposed to anthelmintic treatment.[6,7,15,16]

Evidence supporting the use of refugia to slow anthelmintic resistance

In most situations anthelmintic resistance takes many years or even decades to develop. Therefore, specific evidence that the provision of refugia helps to slow the rate of development of resistance over the long term is lacking,[17] as it would require long-term studies, which are resource intensive and thus rarely funded. Furthermore, multiple different approaches to implementing refugia-based strategies would need to be compared to each other and to “mainstream” anthelmintic-intensive practices in multiple environments and in multiple production systems. This becomes problematic, owing to several options for testing refugia, especially in the case of TST where there are multiple potential decision criteria, and the optimal criteria may not yet be known, and likely will differ when different parasite species predominate. Likewise, parallel issues exist with TT, where considerable environmental differences may exist between properties, which influence the rate of development and survival of the suprapopulation. Consequently, the evaluation of the benefit of refugia, or determination of the optimal refugia strategy, has mostly been evaluated in silico (using computer modeling), rather than in situ (actual field trials). Although computer simulations have many limitations, these provide a useful and timely platform to evaluate which of the many combinations of sources of refugia might be most appropriate for any one of the many different environments.

Many models have been developed, each with their own emphasis and objectives and across several scenarios, including both cattle and small ruminants, and evaluating both TT and TST regimes and parasitologic, pathologic, or performance-based decision criteria (see examples[12,18, 19, 20, 21, 22, 23, 24, 25]). Although differences in the parameters of each of the models exist, the one common element is that in almost all cases they demonstrate the importance of providing refugia to assist in slowing the development of anthelmintic resistance. They also highlight that the rate of reducing anthelmintic resistance development can also be influenced by factors such as treatment efficacy and the environment. For example, the amount of refugia required to provide a beneficial effect (eg, sufficient dilution of resistant worms) is lower in situations where the efficacy of the anthelmintics being used is greater (due to fewer resistant worms surviving) or when the environmental conditions are more favorable for parasite survival outside of the host (due to more worms on the pasture).[19,21,26] Although there is insufficient scope in the present article to cover all of the models that currently exist, key lessons from a select few are detailed here. When evaluating a range of TST options, including the proportion and timing of treatment, a model developed to predict the effects of parasitism with *Ostertagia ostertagi* on weaned calves indicated that the frequency of resistance alleles increased as the proportion of animals treated at any time increased from 10% to 100%.[12] Furthermore, the optimal decision criterion, based on growth per unit change in resistance allele frequency, when a fixed percentage of the herd was treated at any single time was plasma pepsinogen and the worst being average daily weight gain (ADG). However, this was reversed when the proportion treated varied at each time, based on the capacity of animals to reach threshold values for each criteria, in which case the optimum indicator for that scenario was ADG. In many respects, as previously emphasized,[27] this example highlights the complexity of the decision criteria used and what may be perceived as the ideal criteria for any given situation. Nevertheless, these models consistently demonstrate that refugia-based strategies will slow the development of resistance. The real power and usefulness of these models is that they can examine multiple different scenarios regarding host species, parasite species, strategy used, parameters used, treatment efficacy, climate, weather, and so forth (see Hannah Rose Vineer's article, “What Modeling Parasites, Transmission, and Resistance Can Teach Us,” in this issue for more information regarding computer modeling).

Commonly in modeling studies, either parasitologic (fecal egg count [FEC]), pathologic (anemia/pepsinogen), immunologic (antibody) or performance (live weight; ADG; milk production) indicators for treatment are compared. Regardless of the indicator used, all provide a benefit in terms of slowing the development of resistance. However, the on-farm adoption of a regime depends on more than just its ability to provide refugia.[27] Despite known issues with the reliability of FEC to determine parasite burden and need for treatment in a multispecies environment, from a practical perspective one of the challenges with this parasitologic indicator is our current lack of ability to perform pen-side assessment and rapid diagnosis in an inexpensive manner. Pathologic indicators, such as plasma pepsinogen and milk antibody concentrations, can be limited by the same issue and as such may be better suited as indicators for targeted intervention[12] than for TST. In contrast, FAMACHA is a pathologic indicator that can be performed pen-side at virtually no cost, thus allowing for rapid decision making on an individual basis.[28,29] Performance-based indicators (live weight, ADG, milk production) have the advantage of being directly relevant to the producer, easy and relatively cheap to measure, and not limited to or specific for 1 nematode species. However, although models have predicted performance indicators to be effective TST criteria in both cattle[12,24] and sheep,[20] a major drawback is that they are not parasite specific and can be influenced by both the host genotype and nutritional state, factors which need to be taken into account.[11]

There are fewer examples from field trials of evidence demonstrating the importance of refugia in slowing anthelmintic resistance or a comparison of the utility of differing means through which refugia can be supplied. In Western Australia, the use of more than two summer treatments, which is a time when there is little environmental refugia present, was identified as one of the high-risk practices associated with a decrease in ivermectin efficacy.[30] In New Zealand, leaving either the 10% or 20% heaviest lambs untreated in a treat and move scenario slowed the increase in anthelmintic resistance as measured by egg hatch and larval development tests, compared with whole flock treatments.[31,32] In perhaps the only medium-term field study for comparing the use of refugia with so-called "blanket" treatment approaches, production efficiency (performance) was used as the criterion for TST or else TT was used by targeting whole flock treatments at critical times.[33] Both approaches resulted in halving the number of treatments administered to lambs and reducing the rate of decline in ivermectin efficacy over six years from initial values of 95% to 86% compared with 62% in the monthly blanket-treated group. Although the in situ evidence for the importance of refugia is largely based on change in drug efficacy, rather than measured genetic changes in the parasite resistance status, the above-mentioned outcomes are in general agreement with the predicted benefits of providing refugia proposed when evaluated in silico. Refugia-based strategies to slow the development of drug resistance in *Fasciola hepatica* have not been evaluated, either theoretically or empirically,[17] and so are not addressed here.

Targeted treatment and targeted selective treatment to provide refugia for cattle and small ruminants

There are a range of options available to provide refugia as either a TT or TST regime for small ruminants. For cattle the options are fewer, but in most cases the same principles apply regardless of host. A summary of the indicators for anthelmintic treatment that have been developed or explored for cattle and small ruminants are listed in Table 1. Although the aim of each approach is to provide refugia, currently this is not something that can easily be measured.[17] Similarly, the gold standard is change in resistance status of the parasite population, which can seldom be measured with any degree of precision. Other criteria for the success of a regime may be a reduction in the number of treatments administered and/or maintenance of animal performance. These parameters arguably provide at least an indicator for the likely change in selection pressure on anthelmintic resistance and the effect on farm productivity (see Table 1).

Table 1. Potential indicators for treatment of sheep, cattle and goats when part of either a whole herd/mob targeted treatment or individual animal targeted selective treatment regime

Regime Type	Growing Lambs/Calves	Lactating Sheep/Goats/Cattle
	Grazing management	Grazing management
TT (to groups)	Pooled FEC	Parturition
	Plasma pepsinogen	Bulk milk antibody
	Live weight	Grazing management
	Live weight gain	Milk production (high)
	Production efficiency	Body condition score
TST (to individuals)	FAMACHA (*Haemonchus* and fluke)	FAMACHA , BCS, FEC in combination
	FEC	Time of effective contact
	Diarrhea score	Fecundity/parity
	Behavior/lying/grazing time	

Data from Charlier J, Morgan ER, Rinaldi L, et al. Practices to optimise gastrointestinal nematode control on sheep, goat and cattle farms in Europe using targeted (selective) treatments. Vet Rec 2014;175:250-255.

Targeted Treatment in Small Ruminants

TT to groups of small ruminants has been explored in many countries across numerous studies. Overall, a key outcome has been that anthelmintic treatments can be optimized to particular epidemiologically critical time point(s) while maintaining animal production. A good understanding of epidemiologic factors, as well as grazing history and nematode species present, can be combined to determine appropriate drenching strategies. For example, in Italy this knowledge has been used to optimize drenching strategies in dairy goats, with the administration of two treatments per year, associated with parturition. In lambs, using two whole flock drenches at weaning and 4 to 6 weeks later resulted in no loss of weight gain and maintenance of efficacy when compared with monthly drenching.[33] Regular monitoring of FEC within a group of animals with treatment occurring above a certain threshold, as well as combinations of FEC with low mean weight gain, can also be used to direct treatments; and, in the case of the former, evaluation of composite FECs to monitor FEC output, instead of individual counts, can reduce the costs involved, making this a cost-effective strategy. Providing that the time between treatments exceeds the prepatent period of the nematode (typically 3 weeks), that the environmental conditions present are suitable for larval survival, and that the animals remain on the same pasture until reinfected, TT can provide both a source of refugia and adequate parasite control for most situations.

Targeted Selective Treatments for Small Ruminants

Precision livestock farming approaches aim to optimize the contribution from each individual animal on the farm and TST can be considered one such strategy. TST strategies have been developed and evaluated in many countries and, on the whole, shown to be effective in reducing the number of anthelmintic treatments administered, while either maintaining production levels or yielding minimal production losses in comparison with other whole flock (blanket) treatment strategies. Perhaps the most well-known, and certainly first method used to target treatments toward animals suffering from *Haemonchus contortus* infection is the FAMACHA chart.[29,34,35] This is a pathophysiological indicator that monitors anemia levels by comparing the color of the ocular mucous membrane to that on a chart, which then scores the likelihood of the animal suffering from anemia and so requiring anthelmintic treatment. This system was developed for both commercial and resource-poor farmers in South Africa, and has since been tested in more than 36 countries worldwide where *H contortus* infection is common, typically resulting in reductions of anthelmintic use by between 40% and 97%. In the United States, implementation of FAMACHA at the farm level has proven successful. Following validation studies performed first by animal health professionals[36] and then at the farm level,[37] the American Consortium for Small Ruminant Parasite Control (ACSRPC; www.wormx.info) began a program for training small ruminant producers in sustainable integrated parasite management (sIPM), including hands-on instruction for FAMACHA. Approximately 10 years into this program, the ACSRPC conducted a survey of more than 2000 sheep and goat producers trained in sIPM from 2004 to 2008 to determine the impact of this training.[38] Nearly all of the respondents (95.1%) agreed that sIPM training made a difference in their ability to control and monitor parasitism in their herd or flock, and 96.3% used sIPM practices to control GIN. In addition, the vast majority of the respondents reported fewer problems with GIN (71.9%) and were still using FAMACHA to help them make deworming decisions (87.3%) at the time the follow-up survey was conducted. These data emphasize that the optimal benefits of a refugia-based system, such as FAMACHA, are best achieved with personalized training that teaches farmers why this approach is recommended, and how to integrate methods to achieve improved and sustainable parasite control on their farm.

Several performance-based indicators have also been evaluated as part of a TST regime. In dairy goats/ewes, milk yield has proved to be an appropriate indicator, with multiparous nannies/ewes and those with lower milk yield able to remain untreated without any negative effects on the overall fecal egg counts compared with a midseason treatment of all animals.[39] The use of live weight as a marker of treatment need in lambs has had variable results. Although live weight was selected as the most suitable criterion in modeling studies,[20] this has not always been supported in empirical studies[40] where lambs were identified as either heaviest or lightest and either given anthelmintic or not. The untreated animals had lower production scores and higher fecal egg counts than treated animals, with no evidence that heavier animals were more resilient than lighter animals, presumably reflecting that live weight is a measure of the animals historical status rather than simply its current status. This was also observed where treatment was withheld from the heaviest 10% of lambs at each monthly treatment.[32] On three of the five treatment occasions, those that were in the 10% heaviest that remained untreated had significantly lower ADG in the following month than their treated contemporaries, which were lighter. Importantly, however, although individual untreated animals had reduced ADG, the overall mean herd performance was not affected. Thus, refugia were maintained, and presumably anthelmintic resistance was delayed with only minimal herd-level production loss.

In contrast to the studies cited above, other studies have demonstrated that ADG is a useful criterion, but it is influenced by many environmental and genetic factors. By taking into account some of the major non-parasitological factors that influence lamb growth, such as pasture availability, pasture quality, and the relative maturity of the animal, the use of ADG was refined through inclusion of the so-called Happy Factor,[41] that is, the calculation of a production efficiency value whereby the decision to treat animals, or not, is based on their ability to perform at a predetermined efficiency. This approach has been successfully used in research[33] and on commercial farms in a range of lowland and upland environments and in both the United Kingdom and in New Zealand, with a consistent halving of anthelmintic use with no or relatively little associated losses in lamb productivity.[14,42,43]

From a practical implementation standpoint, various treatment indicators do not have to be used in isolation. In fact, there are many studies where a combination of criteria, for example, high FEC, low body condition score (BCS), low diarrhea score, and/or low weight gain have been used to optimize anthelmintic use. In a recent study fecal samples were only collected from ewes if they had low BCS and/or high FAMACHA scores and then only treated if their FEC was over a threshold of 750 eggs per gram of feces.[44] This approach allowed the focusing of the effort required for FEC to those animals that were most likely to be in need of anthelmintic. The results suggested that using BCS can accurately identify animals with FEC over the threshold, and using this approach resulted in treatment of only 36.5% of ewes. In addition, in a Canadian study ewes at lambing were treated only if they exhibited any 1 of 4 criteria, namely ewe age (if the last season grazing was their first season grazing), poor BCS (equal or <2), FAMACHA score of equal to or less than 3, or if they were nursing 3 or more lambs.[28] Because grazing animals are likely to be exposed to an array of parasite species, using multiple criteria seems worthy of consideration to safeguard both anthelmintic efficacy and animal welfare. This approach has been used in the 5-point check system, which has been promoted as an extension of the FAMACHA system.[45] Furthermore, TST do not necessarily need to be within the same stock class. For example, a field study suggested that untreated ewes, when grazed in conjunction with lambs, could provide a source of refugia to most, but not all, nematode parasite species.[46] Also relevant to this study is that the field study was performed to test the results of a computer model, and both the in silico and in situ experiments yielded consistent results.

Targeted Treatment in Cattle

Overall, most of the support for TT in cattle originates from European studies in dairy cattle, which typically have shown the value of either plasma pepsinogen or bulk milk tank enzyme-linked immunosorbent assay (ELISA) optical density ratio (ODR) measurement of *O ostertagi* antibodies for an assessment of whether to treat the whole herd. In lactating adult cattle, the relative ease of collecting bulk milk tank ELISA ODR measurements has been demonstrated as an effective tool for determining the levels of exposure to parasite challenge and the likely response to treatment,[47] even though this may also be influenced by animal age, level of animal confinement,[48] and season.[49] Individual milk ELISA ODR have been shown to correlate well (r = 0.72) with mean individual milk ELISA results;[50] although from this study 3 major conclusions were drawn that: (1) *O ostertagi* ELISA results from individual milk samples could provide more information on the parasitic status of a given herd than a single bulk-tank milk result; (2) a need to include lactation numbers when interpreting ELISA results from individual milk samples, which might have reflected higher acquired immunity after repeated exposure to GIN infections; and (3) that the value of *O ostertagi* antibody level in individual cow milk samples remains ambiguous as a means to predict individual production responses after anthelmintic treatment. In a meta-analysis,[51] it was reported that anthelmintic treatment based on the bulk milk ODR to *O ostertagi* antibodies could be expected to yield an overall combined estimate of increase in milk of 0.35 kg per cow per day.[49] Thus, the approach of bulk milk antibody ODR cannot only provide an indicator for the need for treatment of cows infected with *O ostertagi*, but also of quantification of the expected benefit. All of these strategies will help to maintain refugia, while simultaneously providing both good parasite control and levels of productivity.

Targeted Selective Treatment in Cattle

By comparison with the number of studies carried out in small ruminants there have been relatively few that have investigated TST regimes in cattle. As mentioned above, investigations in lactating cattle have included milk ODR to parasite antibodies, which can be taken on an individual basis, although the preference is now to use a bulk milk ODR test as part of a whole herd-targeted regime. Conversely, the individual cow milk production response to treatment over time was relative to the time of effective contact (TEC) with parasites on pasture before first calving.[52] Although a TEC of 8 months was identified as the optimal indicator for a TT treatment, the high level of individual cow variability associated with number of parity, days in milk, and ODR suggested that taking these parameters into account may provide a useful TST indicator. For growing cattle, ADG has gained favor as a performance indicator of choice. This presumably reflects the relative ease with which this can be recorded and its relevance for cattle to reach target weights. More specifically, Swedish studies have suggested that measurements of midseason ADG (6–8 weeks after turnout) can provide a simple and practical means of identifying whether animals should be given an anthelmintic or not; they reported that ADG at this time provided the best predictor of final season live weight, with an optimal cutoff target weight of 0.75 kg per day at midseason.[53] This value is in general agreement with both the required growth rates needed to achieve anticipated mating weights and also the New Zealand studies,[54,55] which used breed-specific predetermined live weight targets to set ADG targets, ranging from 0.30 to 0.68 kg per day in winter and summer, respectively. Overall, these New Zealand-based studies showed a 47% and 72% reduction in anthelmintic use, with an associated 2% and 5% reduction in ADG compared with a monthly whole herd treatment. Greater reductions in both anthelmintic use and animal performance have also been reported in Swedish studies[56] where an anthelmintic was administered only to those TST calves with the ADG of approximately one-quarter of the continuously treated animals; this resulted in a reduction of both anthelmintic use by 92% and growth from 0.39 to 0.61 kg per day to 0.36 to 0.50 kg per day. Overall, although the number of TST studies in cattle are limited, using ADG as a decision criterion does seem to provide a useful means of reducing anthelmintic use while safeguarding animal productivity.

As with small ruminants, setting TST indicators based on animals reaching predetermined performance targets is problematic because attributes, such as growth, are greatly influenced by nonparasite factors. These can be alleviated somewhat, however, through the use of one of a range of growth calculators that are freely available on the Internet but these still do not fully account for individual animal variability. Alternatively, recent interest in changes in animal behavior associated with parasitism may provide a more sensitive method of individualizing treatment. For example, differences in daily and diurnal activity patterns, such as an increase in the number of lying-bouts in parasitized cattle compared with nonparasitized cattle[57] and increased total grazing time after anthelmintic treatment.[58] The potential to monitor individual animal behavior as an indicator of welfare and parasitologic status has recently been made possible through the use of accelerometers, GPS, fixed cameras and drones, combined with sophisticated analysis algorithms. Though still in its early stages of refinement, this is an exciting prospect for the future refinement of TST indicators in cattle.

All of the approaches discussed above for TST rely on the measurement of specific production and or pathologic parameters. However, in many cattle operations, particularly small holders, this type of data collection is often impractical given the farm management structure, and thus will rarely be done by the farmer. Because true TST is not possible without collection of animal-specific data, an alternative approach to maintain refugia is to perform selective nontreatment. Here, the farmer treats most the herd, but leaves 10% to 20% of the cattle untreated. These untreated animals can be selected randomly or based on visual characteristics (eg, leave the best looking animals untreated). This strategy will provide a source of refugia, and based on available data, the loss of productivity will be rather small. Furthermore, when using this strategy it is recommended to use a combination of anthelmintics to maximize the level of efficacy from the treatment. Given the high levels of anthelmintic resistance in many areas, using both selective nontreatment of 10% to 20% of the herd combined with a combination anthelmintic treatment, will likely yield better overall parasite control and production compared to using a drug with suboptimal efficacy in the entire herd (see Ray M. Kaplan's article, "Biology, Epidemiology, Diagnosis, and Management of Anthelmintic Resistance in Gastrointestinal Nematodes of Livestock," in this issue for more information on anthelmintic resistance and optimal strategies for using anthelmintics).

Future prospects and challenges with refugia-based approaches

Incorporating refugia into anthelmintic treatment regimes generally requires a change in farming practice and farmer mindset. However, in many instances current parasite control practices are no longer effective and are unsustainable. Thus, continuing to use traditional herd-wide treatments often is no longer a reasonable option. This is reflected in the current recommendations of several national parasite advisory schemes, such as Wormwise in New Zealand, Wormboss in Australia, SCOPS in the United Kingdom, and the ACSRPC in the United States. Including refugia invariably requires greater inputs of some degree, whether that be time, labor, or investment in technology. In part this is balanced in the short term by the generally lesser need to treat animals, thus saving in anthelmintic costs, and, in the long term, maintenance of anthelmintic efficacy. The economic impacts of refugia-based strategies are yet to be comprehensively analyzed, but limited data are available. Studies using FEC to target treatment and reduce anthelmintic use in the United Kingdom showed savings of £660 ($1000) per annum.[59] However, farmers will also consider the whole system rather than just savings in costs of anthelmintics. Using a combination of precision livestock farming approaches (TST in lambs and optimized ewe feeding over winter) on an upland/hill flock showed that labor can be reduced and costs saved. Labor was reduced by 36%, and anthelmintic use by 40%, compared with a more conventional approach whereby the animals were dealt with in batches. This equated to savings of £3 ($4.50)/ewe.

There is no single way for optimally providing refugia. Rather, there are a range of options depending on the complexity and diversity of both the parasite epidemiology and farming systems.[27] Each of these has its own advantages and disadvantages, but it is worthwhile considering that the incorporation of refugia does not have to be an all-or-nothing approach. For example, it may be incorporated into part of the system, such as a TT or TST directed to replacement female lambs, which has the potential to provide sufficient refugia to allow for more suppressive parasite control in animals destined for slaughter and for which production loss is unacceptable to the farmer. It is generally agreed that any attempt to provide refugia, even if on a small scale, will be expected to provide some benefit in slowing resistance compared with the alternative.

Although it must be left to the individual farmer/advisor to identify what fits best with a given production system, regardless of what option is selected, a major shift in mentality is required to make these approaches common practice in parasite control.[11] This is particularly the case because reduced development of anthelmintic resistance will not be readily apparent to farmers.[12] Although the provision of refugia can be achieved through relatively simple means (ie, leaving some animals untreated at each time) the relative complexity and compatibility of TT or TST strategies need to be taken into consideration by the farming industry[60] and their application may be hindered by farm-specific factors. Among others, a lack of detailed socioecological analysis and understanding of farmers' preconceptions, attitude, behavior, and beliefs regarding the implementation of TT/TST approaches are among current barriers to their uptake.[11] Moreover, it may be that the delay in anthelmintic resistance alone may not be enough of an incentive. For example, TST in combination with electronic animal identification provides an opportunity to not only identify and select animals that were less reliant on anthelmintics as replacements,[61] but also provide a signal to the markets that the saleable product has been produced sustainably with responsible use of chemicals in food-producing animals. Therefore, benefits of refugia-based strategies for parasite control can extend beyond the provision of refugia, and these benefits are likely to increase in the future.

Disclosure

The authors have nothing to disclose.

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