



Dynamics of epidemiological intelligence for exploitation in effective worm management in sheep – A Rajasthan experience

D SINGH¹, C P SWARNKAR² and P K SANYAL³

Central Sheep and Wool Research Institute, Avikanagar, Rajasthan 304 501 India

and

College of Veterinary Science and Animal Husbandry, Anjora, Durg, Chhattisgarh 491 001 India

Received: 6 September 2014; Accepted: 12 June 2015

ABSTRACT

Being of ubiquitous nature and omnipresence of the gastrointestinal (GI) parasites, their management presents a difficult challenge following wide-spread emergence of anthelmintic resistance. Anthelmintics have a definite role to play in worm management but their frequency of use should be minimised to the extent possible and the available resources of anthelmintics could be used judiciously by exploiting the knowledge of parasite epidemiology. The present communication discusses different aspects of worm biology and their interaction with environment, host and managerial practices. The bioclimatographs suggested existence of suitable conditions for translation of exogenous stages of *Haemonchus contortus* from late May to late September in semi-arid region and from mid June to late August / September in arid region. Based on real-time observations, different strategies were developed and tested for efficient management of GI nematodes in sheep flocks of Rajasthan. The agro-climatic conditions and lambing pattern do not favour the development of strongyle larvae during December-June, resulting in absence of typical peri-parturient rise in faecal egg counts (FECs). However, the epidemiology of strongyle worms showed the possibility of hypobiosis. An initial rising trend in FECs in June could be probably due to resumption of development of hypobiotic worms within the host, giving peak of infection in July and providing the source of pasture contamination during monsoon. The decline in FECs in the following months may be due to spontaneous occurrence of “self-cure” phenomenon. The GI parasite populations in small ruminants are highly aggregated and over-dispersed, with around 80% of the worms found in only 20-30% of the host. Thus, requirement for treatment is a reflection of the genetic basis of host variation in either innate or acquired resistance to parasites or resilience. The over-dispersion phenomenon was used in the form of targeted selective treatment and for breeding for resistance / resilience to parasites ultimately with the aim to increase the size of *refugia*, maintain anthelmintic efficacy and cost-effective worm management.

Key words: Anthelmintic resistance, Epidemiology, Gastrointestinal nematodes, Rajasthan, Sheep, Worm management strategies

Worm infection is the single most important animal health problem affecting small ruminant production around the globe. Being ubiquitous in nature, the parasites and omnipresence in grazing livestock, management of worms presents a particularly difficult challenge following wide-spread emergence of anthelmintic resistance (Sanyal 1996). Owing to favourable climatic conditions for translation of pre-parasitic stages and in absence of alternate control strategies, control of parasitic gastroenteritis in ruminants is primarily attempted by the frequent use of anthelmintics at short intervals, particularly in intensive and semi intensive management systems, which has been shown to result in

the emergence of very high levels of anthelmintic resistance (Singh *et al.* 2002). Anthelmintics, though singularly blamed for the failure of parasite control programme world over, cannot be sidelined altogether. They have a definite role to play in sustainable parasite control programme but their frequency of use should be minimised to the extent possible and the available resources of anthelmintics could be used judiciously by exploiting the knowledge of parasite epidemiology, both in the host and on the pasture (Sanyal 1998). Traditionally the worm control in livestock is typically based on frequent treatments (3-5 times) throughout the year without considering the prevailing climate, status of infection in host and on pasture and grazing practices. Further, simultaneous deworming of sheep flocks after shearing, *en masse* deworming at the face of any disorder and outbreaks (real or predicted) and unsystematic use of anthelmintics in animal health camps

Present address: ¹Principle Scientist (e mail: dherindra.singh56@gmail.com), ²Scientist (Selection Grade) (e mail: swarnkarp@yahoo.com), Division of Animal Health, ³Professor and Head (e mail: sanyalprabir54@gmail.com), Department of Veterinary Parasitology.

are routinely followed (Swarnkar and Singh 2010b). Such haphazard and uncontrolled use of drugs further aggravated the problem of drug resistance in grazing livestock.

The available information revealed that over the years there is dramatic change in parasite prevalence, intensity and biology due to change in climate, grazing resources, rearing practices and intensive use of drugs. We do not know if this is due to climate change, drug selection pressure, change in production systems or indeed a function of them all. However it is clear that our worm control strategies need to be refined to meet the challenges of changing epidemiological scenario.

It is now realised that the single most important factor influencing the spread of anthelmintic resistance is the dwindling size of *refugia*. The free-living stages of parasite that are not exposed to anthelmintics (*refugia*) provide a source of susceptible allele to dilute resistant allele in the population of parasite in a given area (Singh and Swarnkar 2008). In view of resistance menace, the target stages of parasites to break their life cycle shifts today from adult parasites in the host to pre-parasitic stages on the pasture. Such a quantum change in the present day worm management practices, require the help of ever changing dynamics of epidemiological intelligence of gastrointestinal nematodes.

Dominant nematode species in Rajasthan

To formulate effective and sustainable worm management programme in small ruminants, the knowledge on type of parasite species, their predominance, prevalence and economic significance in particular agroclimatic condition is essential. The common gastrointestinal nematodes of sheep are *Haemonchus contortus*, *Trichostrongylus axei*, *T. colubriformis*, *T. vitrinus*, *Nematodirus fillicolis*, *N. spathiger*, *Bunostomum trigonocephalum*, *Gaigeria pachyscelis*, *Cooperia curticei*, *Oesophagostomum columbianum*, *O. venulosum*, *Chabertia ovina*, *Trichuris ovis* and *Strongyloides papillosus*. However, only a few are dominant (e.g., *H. contortus*, *T. axei*, *T. colubriformis*, *O. columbianum*) and had economic impact on sheep production in Rajasthan (Swarnkar et al. 2008).

Free-living stages

Seasonal dynamics: The dynamics of strongyle larvae on coproculture exhibited predominance of *H. contortus* with higher proportion (>80.0%) from April to October. The proportion of *Trichostrongylus* spp. in coproculture was found to increase moderately from December to January in semi-arid and from December to April in arid Rajasthan. Relatively higher prevalence of *O. columbianum* larvae was observed during summer in both the agroclimatic conditions. The pattern suggests that warm, moist season with adequate rainfall is more suitable for survival of *H. contortus* larvae. Within agroclimatic zone, management of flocks had significant influence on the type of strongyle larvae which might be due variation in anthelmintic types

used for management of worms. The optimum conditions for translation of *H. contortus* include total monthly rainfall >50 mm and a mean monthly maximum temperature >18.3°C. *Trichostrongylus* spp requires a total monthly rainfall >50 mm and mean monthly temperature of 12.8 to 18.3°C for their translation on pasture. In Rajasthan, rains occur during July-August but the mean maximum temperature was >20°C throughout the year in semi-arid region. The higher prevalence of both *T. axei* and *T. colubriformis* on coproculture in arid field might be due to prevailing higher humidity during winter in northern part of Rajasthan. Though the requirement of environmental conditions for development and survival of *O. columbianum* larvae are almost similar to that of *H. contortus*, their higher prevalence during summer and winter indicate that sporadic rainfall during winter and spring makes the environment more conducive for their development.

Influence of drug type on nematode parasite prevalence: Closantel (CLS), a long acting narrow spectrum salicylanide derivative is reported to have persistent anthelmintic activity against haematophagous GI nematodes for several weeks. As sheep are usually infected with mixed species of GI nematodes, there is possibility that if CLS is used against mixed infection of GI nematodes, it may select non-haematophagous nematodes in population and after a couple of years genetic diversity may be altered in that particular region.

Influence of macro-climate: The depiction of relationship between disease outbreaks and the climate facilitating the monitoring of the outbreaks due to *H. contortus* dates back to 1948, as originally proposed by H.M. Gordon, the father of epidemiology of internal parasitism of sheep. Construction of bioclimatographs was the first rational attempt to utilize climatic observations to explain important features of epidemiology of helminthic infections. The predictive value of bioclimatographs largely depends on a given set of climatic factors and a sound knowledge of the epidemiology of the GI parasites of animals of a particular locality of interest. To visualize the effects of temperature, rainfall and relative humidity, bioclimatographs were prepared in which total rainfall (TRF) or relative humidity (RH) is plotted against the T_{max} or T_{min} for the month. The limits of suitable climatic conditions were taken as total monthly rainfall to the tune of 50 mm or more with average monthly T_{max} ranging between 18 and 37 °C for *H. contortus* and comparable rainfall with temperature ranging between 6 and 20 °C for *Trichostrongylus* spp (Swarnkar and Singh 2011, 2013). Among the three states in the Western region of country, bioclimatographs (based on climatic data from 1991 to 2011) suggest that suitable period for translation of exogenous stages of *H. contortus* was too short (July to late August) in arid Rajasthan which increased from June to early September in semi-arid Rajasthan, followed by late May to late September in Gujarat and from mid May to mid October in Maharashtra. Like-wise suitable period for translation of exogenous stages of *Trichostrongylus* spp. was almost similar in all three states of Maharashtra, Gujarat

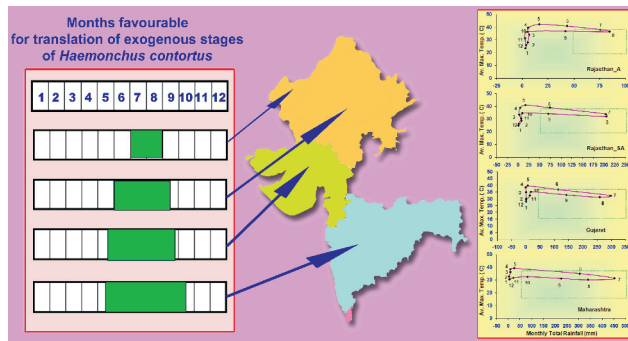


Fig. 1. Bioclimatographs for *Haemonchus contortus* in Western region (1991-2011).

and Rajasthan and it ranged from October to early March / April. The period was marginally longer in Gujarat state (Figs 1, 2).

Decade-wise bioclimatographs for *H. contortus*: In semi-arid Rajasthan, the climatic data exhibited an increasing trend in mean monthly maximum temperature from

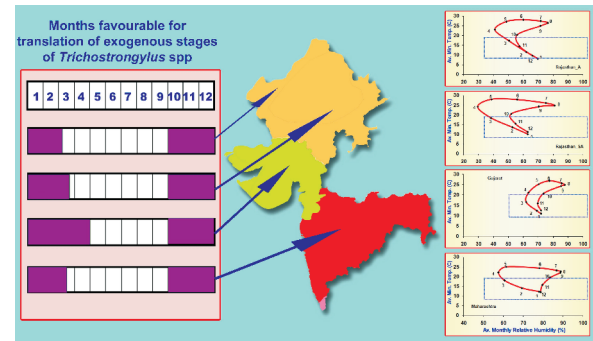


Fig. 2. Bioclimatographs for *Trichostrongylus* spp in Western region (1991-2011).

February to November over the span of 100 years. However, this rise was within threshold limits required for optimum development of exogenous stages of *H. contortus*. There was sufficient monthly total rainfall recorded from June to September in all the decades except in 1911-1920, where it ranged from May to October. The bioclimatographs

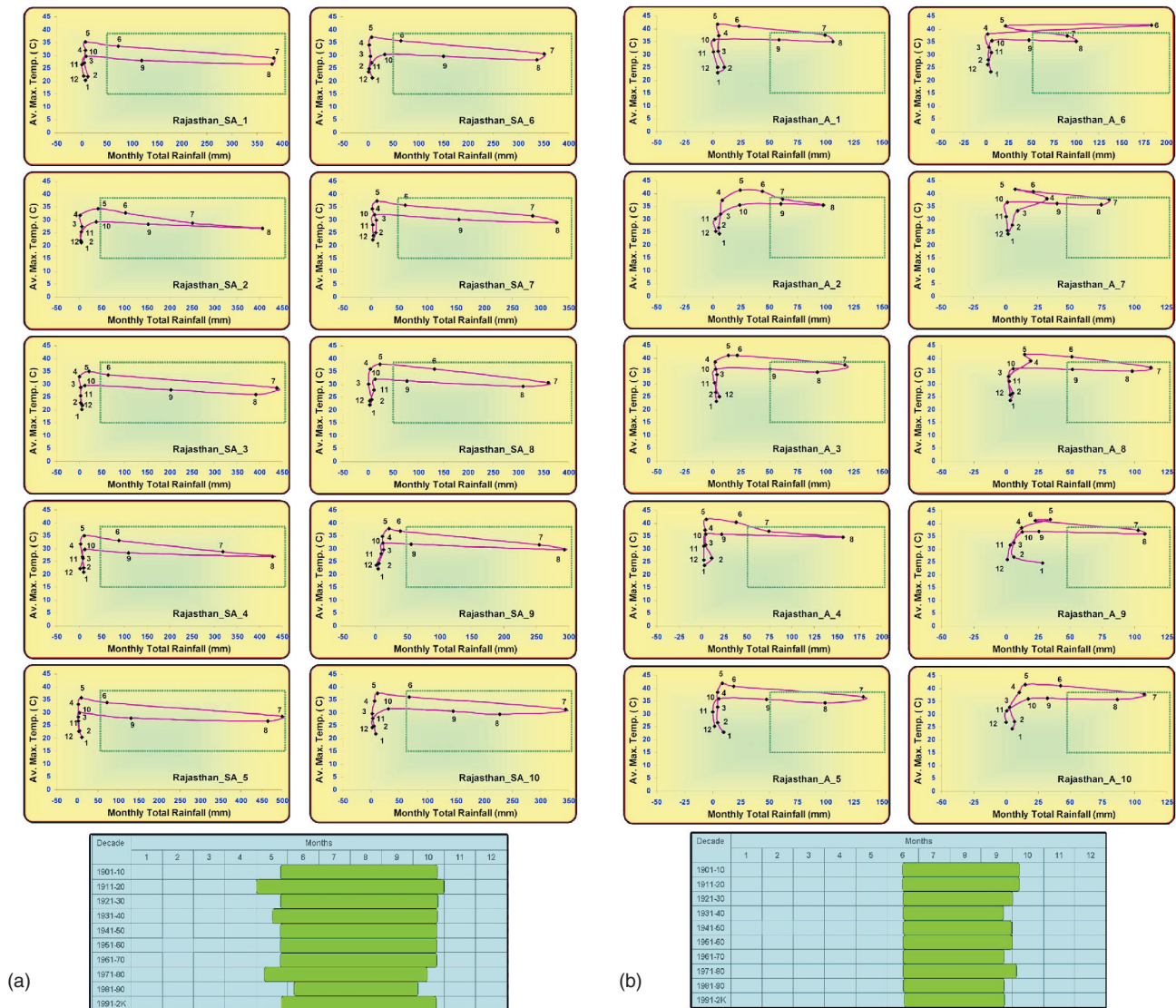


Fig. 3. Decade-wise bioclimatographs and changes in favourable period for translation of *H. contortus* in Rajasthan. (a) semi-arid, (b) arid.

suggested existence of suitable conditions for translation of exogenous stages of *H. contortus* from late May to late September in various decades (Fig. 3).

Like-wise in arid Rajasthan, climatic data over the decades showed a marginal rise in average monthly T_{max} from January to April. The usual occurrence of sufficient monthly total rainfall was from July to September in all the decades with minor variation during 1971-1980 (June to September), 1961-1970 and 1981-2000 (July to August). The decade-wise bioclimatographs showed that the onset of suitable conditions for translation of exogenous stages *H. contortus* in arid Rajasthan was from mid June and this remained constant over the entire period of 100 years. Suitable conditions seem to persist up to late August to September depending on the length of monsoon.

The ability to predict the timing and magnitude of infection level in host and on pasture and plan grazing and worm control strategies are the key requirement of preventing losses caused by GI nematodes. Since last six decades time-to-time introduction of efficacious chemotherapeutics put the interest on role of biology of free-living stages of parasites in corner but development of anthelmintic resistance now forces us to resurrect this discipline and give full attention to it in formulation of strategies for worm management. Climatic consideration in combination with grazing history and practices can be taken into account in evaluating expected levels of *refugia* and thus treatments can be avoided at times when *refugia* are likely to be small. Anthelmintic treatment of livestock for management of strongyle parasites should be restricted to the active parasite transmission season. Thus present strategies of frequent deworming as practiced should be suspended. In our situation more attention and research is needed for a thorough quantitative discipline of strongyle larval bionomics and a better understanding of their basic epidemiology on regional basis. Furthermore, the approach should be diverted towards rationalization of anthelmintic use particularly timing of their application through formulation and implementation of simulation and / or

forecasting modules capable of predicting pasture larval infectivity on regional basis.

Bionomics of infective larvae on pasture: The major epidemiological factor influencing worm burden in grazing animals is the number of infective (L_3) larvae ingested with pasture. The development of L_3 within the faeces, their migration on herbage is a key factor in parasite transmission to grazing livestock. The rate of development to the L_3 is dependent on the temperature. Rain (moisture/relative humidity) tends to increase the infectivity of pasture by assisting in the movement of L_3 out of faeces and by providing the film of moisture necessary for L_3 to migrate on to herbage. A low humidity accompanied by either low or high temperature inhibits vertical migration and the maximum numbers of infective larvae are found during rainy season. Understanding these factors can explain differences in infectivity of pasture for grazing livestock.

Early in the free-living phase, the developmental success of *Haemonchus* and *Trichostrongylus* spp. is limited by susceptibility to cold temperatures with *Haemonchus* spp. being more susceptible. Once the infective stage is reached, the influences of temperature and moisture on survival are less important, resulting in considerable survival times under conditions lethal to pre-infective stages (Table 1). However, hot-dry conditions can be lethal for infective larvae of both species, while extreme cold is also lethal with significant species variation (O'Connor *et al.* 2006).

The larval development of *H. contortus* occurs optimally at relatively high ambient temperatures, high humidity and herbage and high rainfall (Urquhart *et al.* 2000). Relatively low rate of *Haemonchus* larvae during winter months may be attributed to unfavorable climatic conditions like low temperature that retard the development of free-living stages, as at 9°C no development of these larvae takes place (Soulsby 1982). *Trichostrongylus* spp. are generally considered as cool-season parasites (Southcott *et al.* 1976), as they thrive best at mean monthly temperatures ranging from 2.8 to 18.3°C and disappear when temperature exceeds 20°C (Gordon 1953). The eggs and L_3 of *Trichostrongylus*

Table 1. Environmental effect on different stages of strongyle worms of sheep

Nematode species	Life cycle stage			
	Unembryonated egg	Embryonated egg	Pre-infective larvae	Infective larvae
<i>Haemonchus contortus</i> Temperature range for development of egg to infective larval stage Optimum: 25-37°C Overall: 11-41°C	High susceptibility to cold and desiccation High mortality at <10°C	Susceptible to cold and desiccation Low hatching in the absence of moisture and/or at <10°C	High susceptibility to cold and desiccation	Optimum survival under warm and moist conditions Poor survival in dry climates (warm or cool) and sub-freezing winter
<i>Trichostrongylus colubriformis</i> Temperature range for development of egg to infective larval stage Optimum: 22-33°C Overall: 6-39	Intermediate susceptibility to cold and desiccation High mortality at <5°C	Intermediate susceptibility to cold Low susceptibility to desiccation	Susceptible to cold and desiccation High mortality at <5°C	Optimum survival under warm or cool moist conditions Poor survival over sub-freezing winters

spp. have been reported to have a high ability to survive under adverse weather conditions like cold or desiccation (Urquhart *et al.* 2000).

Since, environmental conditions vary from place to place, studies on the bionomics of the larvae under local conditions are of immense help in planning the worm management strategies. In semi-arid Rajasthan, the study on pasture artificially contaminated with *H. contortus* contaminated faeces showed that larvae survived for maximum period (up to 9 weeks) during September followed by August and November (8 weeks). High temperature, low humidity and scanty rainfall during summer months (March to June) were found unsuitable for translation of infective larvae of *H. contortus* on pasture (Swarnkar *et al.* 1997). The mean daily rainfall of 4.5 mm with relative humidity to the tune of >26% is found sufficient for the eggs to develop to infective larvae on pasture in this area. Thus, in semi-arid condition contaminated pasture should be kept free from grazing at least up to 9 weeks to make it parasitologically safe pasture for grazing w.r.t. effective management of haemonchosis.

Pasture infectivity profile in Rajasthan: More than 90% of the total parasite population exists outside the host as eggs or larvae in the faeces or in the soil. In both the agro-climatic region of Rajasthan and management system of sheep rearing higher PLB occurred during monsoon season except in arid field where it was marginally higher during summer (Fig. 4). A small peak in PLB during February is attributed to favourable environmental as well as resumption of hypobiotic worms and increased contamination of pasture by faeces from ewes in lambing. The PLB started rising with pre-monsoon shower and reached to peak in August (Swarnkar *et al.* 2008, Swarnkar and Singh 2013). Absence of infective larvae on pasture from January to April in community grazing land might be because of variation in grazing pattern and lambing in field flocks. During these months, the flocks in field area are mainly maintained on post-harvested fields or on top feeds and lambing is almost negligible compared to utilization of same pasture and major lambing in farm flocks.

Migration of infective larvae on herbage: Larvae must move away from the faecal mass and onto the surrounding herbage to be ingested by grazing livestock. This movement is facilitated by a continuous film of moisture on herbage. Where moisture is not limiting, temperature will have a

greater influence over migration (Stromberg 1997). Silangwa and Todd (1964) found that migration was favoured by higher humidity with significantly more larvae moving at 95% compared with 56% relative humidity. Larvae were also more likely to climb wetted leaf blades. Low temperatures adversely affected the ability of the larvae to climb herbage with significantly more larvae climbing at 27°C than 4°C. Several studies have reported differences between nematode species on the rate of migration from the faecal mass. *H. contortus* and *T. colubriformis* have both been observed to migrate rapidly onto herbage once development was complete with negligible numbers remaining in faeces within a few weeks while others may remain up to 10-18 months.

Herbage factors such as density and height will determine the levels of light, moisture and temperature at different height strata within the sward and influence the distribution of larvae. Typically taller herbage will be moist and cooler than short herbage of the same density and dense herbage will be cooler and moist than sparse herbage. Crofton (1948) established that high humidity occurred in the base of the sward even when atmospheric humidity was low. Van Dijk *et al.* (2009) reported that a similar vertical gradient would be expected to exist for UV irradiation. In this study it was suggested that exposure to UV may explain why larvae may constantly move on and off herbage, secondly why around 90% of larvae are generally recovered from the base of the herbage and thirdly why the height to which larvae migrate appears to be related to leaf shape.

Horizontal distribution of L_3 larvae on pasture: A few larvae migrate further than 30 cm from the faecal pat even after significant time and rainfall (Rocha *et al.* 2008). In the controlled laboratory conditions more than 90% of the larvae were transported passively by splash droplets rather than by active migration. On pasture, faecal pats are often surrounded by tufts of rejected grass and will restrict horizontal movement of splash droplets resulting in larvae falling a few cm from the pat. Where splash droplets could move freely L_3 were found up to 90 cm away from the pats. In sub-temperate Tamil Nadu with an annual rainfall of 871.8 mm and minimum and maximum temperatures of 0° and 22° C, the infective larvae migrates mostly up to 20 cm, but their numbers that migrated even up to 50 cm both in short and long grasses indicated biotic importance (Sanyal 1989a).

Vertical distribution of L_3 larvae on pasture: In the summer months, the majority of larvae were found in the soil than the 'mat'. In the spring and autumn more larvae were found in the 'mat' and fewer in the soil or on the foliage whilst in winter larvae were concentrated in the 'mat'. Silangwa and Todd (1964) observed that even under favourable conditions only a small proportion (2-3%) of larvae applied to the soil actually climbed the foliage. Of these 59% were found in the bottom 2.5 cm, 27% up to 5cm, 10% to 7.5 cm, 3% to 10 cm and 1% above this. In sub-temperate Tamil Nadu, the larvae remained within 5 cm length of the grass from the soil when rainfall was poor

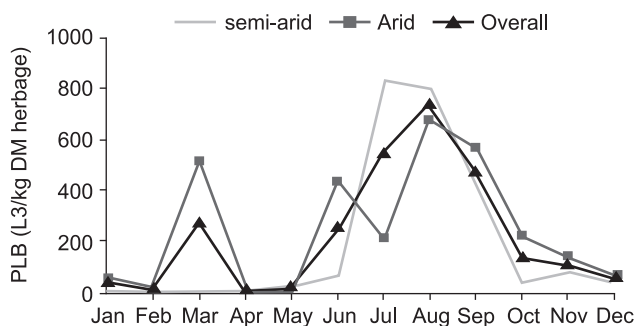


Fig. 4. Level of pasture infectivity pattern in grazing area in Rajasthan.

but migrated >15 cm vertically along the grass blades when there was sufficient rainfall (Sanyal 1989a).

Parasitic stages

Peri-parturient rise (PPR): It refers to an increase in the number of nematode eggs in the faeces of animals around parturition and during lactation due to a temporary relaxation in immunity at about parturition period (O'Sullivan and Donald 1970) and associated with changes in the circulating levels of the prolactin. Isolated reports on spontaneous elimination of worms and PPR of GI nematodes in certain geographical areas in India are available. Increase in strongyle egg count occurred in March-April coinciding with lambing season in Kashmir Valley. The PPR was found responsible for contamination of pasture during the spring season which in turn contributed to the built up of infection in lambs (Dhar *et al.* 1982). The exact cause of PPR is not known, if this is due to resumption of development of arrested worms or due to an increase in number of newly acquired infection by the host consequent to loss of resistance. Hypobiotic behaviour of *H. contortus* was observed at Kodai Hills in Tamil Nadu (Sanyal 1988a) which result in sudden increase in eggs and worm counts in March inspite of fact that the larval burden on pasture and egg counts in animals remain minimum in February. Gupta *et al.* (1986) reported that agro-climatic conditions of Haryana were favourable for development of trichostrongylid larvae on pasture leading to occurrence of PPR in sheep (Gupta *et al.* 1987) during February-April.

In Rajasthan, the agro-climatic conditions do not favour the development of strongyle larvae during December-June (Swarnkar *et al.* 1997) resulting in non-availability of source of infection for ewes and absence of typical PPR (Singh *et al.* 1997). Further Swarnkar *et al.* (1998a) observed non-significant difference in FEC in different breeds of sheep over the 12 weeks post-lambing, ruled out presence of PPR phenomenon in this region. Lambing pattern in field flocks revealed that majority of ewes in flocks are in lambing / lactation during October to February and agro-climatic conditions of the state does not favour the translation of worms from December to June resulting in non-availability of source of infection for lactating ewes (Swarnkar and Singh 2010a). Thus, the strategic anthelmintic drench as practiced by farmers in the month of February-March could be withdrawn without hampering the flock productivity (Swarnkar *et al.* 2008). Further, avoidance of deworming during this period enables survival of susceptible parasites with in the host (as hypobiotic) which in turn leads to help in reducing selection pressure for anthelmintic resistance and maintaining the efficacy of anthelmintics by increasing the size of *refugia* (Singh and Swarnkar 2008).

Hypobiosis: It is a temporary cessation in development of a nematode parasite at a precise point in its parasitic phase of development. The abomasal (*H. contortus* and *T. axei*) and small intestinal worms (*T. colubriformis*, *Cooperia* and *Nematodirus*) are capable of arresting their development at L₄ stage and persisting for long period in a state of dormancy.

On return of favourable conditions they resume their development. Although there are apparently different circumstances which initiate hypobiosis, most commonly the stimulus is an environmental one received by the free-living stages prior to ingestion by the host. Hypobiosis is considered as an evolutionary adoption which delays egg production and death of worms until the following monsoon when eggs deposited on pasture have a higher chance of continuing the worm lifecycle. It has importance in epidemiology of GI nematodes in sheep because:

- It creates the major way by which worms survive and maintain its population during harsh climatic extremes of winter and summer
- Resumed development of hypobiotic larvae during June might be responsible for clinical disease in yearling sheep and peak parasitic activity on pasture during monsoon
- The worms arising from hypobiotic larvae in sheep are an important source of pasture contamination during monsoon period

A period of drought may also be responsible for a sudden massive invasion of worm larvae. On the other hand, adverse conditions, such as the drying of ponds or winter ice, generally mean fewer or less vigorous parasites, which may be conditioned for arrested development. Blitz and Gibbs (1972) suggested that the falling autumn temperature provided an environmental stimulus, which caused infective larvae to become inhibition-prone. In the absence of significant hypobiosis during the dry season the only alternative strategy for survival of *H. contortus* is to exist as adult in the host. Owing of the high fecundity of *H. contortus* residual proportion of female worms in the total population as seen during the dry season could be advantageous for the transmission of parasites from one rainy season to the other and for the successful repopulation of the environment during the favorable season (Fakae 1990).

From Indian point of view, Gupta *et al.* (1987) did not find hypobiosis in sheep and goat from Haryana. From Tamil Nadu, Sanyal (1988b, 1989b) reported hypobiosis in *H. contortus* of sheep and found that the exposure of larvae in cold climate on pasture might be the factor inducing hypobiosis. Thus, though the pasture larval contamination was lowest in winter, the possibility of *H. contortus* larvae becoming inhibited as an early L₄ stage during winter was maximum. These in turn, may become the potential source of pasture contamination in spring coinciding with the lambing. The epidemiological profile of strongyle worms in sheep flocks of Rajasthan exhibited possibility of hypobiosis (Singh and Swarnkar 2013; Swarnkar and Singh 2012c) possibly associated with climatic changes unfavourable to the continued development of the free-living stages of the nematodes in the external environment. Investigations on hypobiosis showed a sharp decline in abomasi harbouring only adult worms from November to April (nil to 25%) compared to other months (28.6 to 69.2%). The post-mortem and faecal examination from sheep showed that both adult *H. contortus* and L₄ were

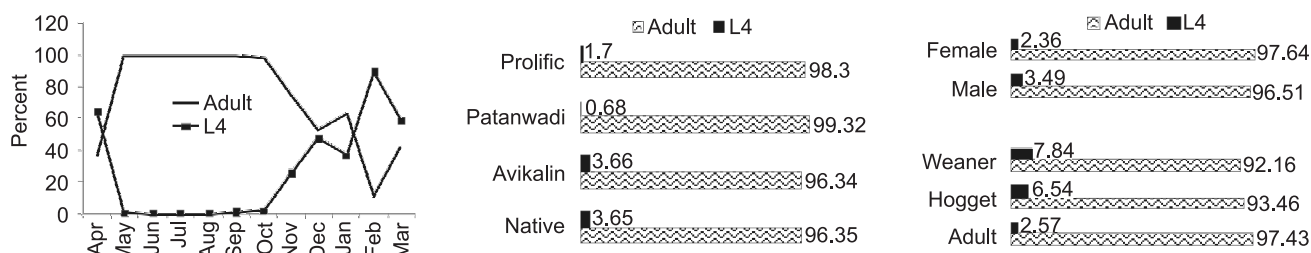


Fig. 5. Adult: L4 in abomasi of naturally infected sheep.

present in all the months. The examination of HCl-pepsin digested abomasal mucosa revealed presence of significant number of hypobiotic *H. contortus* larvae from September to April. The monthly mean number of adult *H. contortus* in sheep (irrespective of age and sex) remained >150 per abomasum from June to September. The number of L₄ in abomasal mucosa was 1.0 / abomasum from May to August and started rising from September and reached to a peak in January followed by decline in subsequent months. The analysis of adult: L₄ in abomasi showed sudden rise in proportion of L₄ from October which persisted at high up to April (Fig. 5). An inverse relationship between proportion of L₄ and age of animal with maximum in weaners (7.84%) followed by hoggets (6.54%) and minimum in adults (2.57%). The observation suggested young animals as possible source of infection for pasture contamination after dry spell. Sex of animal had non significant influence on adult: L₄ in abomasi. The breed-wise proportion of L₄ in abomasi ranged from 0.68% in Patanwadi breed to 3.66% in Avikalin breed. Thus it would appear that factors responsible (probably cool and dry conditions) for induction of hypobiosis were probably dominant during October/ November to April and it can be derived that dryness is more conducive to development of infective larvae.

Resumption of development occurs in response to yet unidentified stimulus in June but is thought to be related with nutritional and walking stress along with suitable climatic conditions with pre-monsoon showers. Hence the decrease of hypobiosis and increased number of adult worms in abomasums during June to September may be due to the onset of the rainy season which is suitable for *H. contortus* to propagate and for the arrested larvae to develop into adult worms.

Self-cure: Stoll (1929) first reported "self-cure" phenomenon in sheep with expulsion of *H. contortus* and protection of the animals thereafter against any significant amount of further infection. Gordon (1948) observed that "self-cure" was usually seen when there was a fresh growth of pasture, along with an increased *H. contortus* larval intake and it was of short duration. Stewart (1950) found that the intake of large doses of L₃ of *H. contortus* was the exciting cause of the "self-cure" phenomenon. Stewart (1953) concluded that there was a reaction of the host associated with allergic sensitization and an oedematous condition of the abomasal mucosa after the administration of larvae.

The long-term study in sheep flocks of Rajasthan showed an initial rising trend in FECs in June (due to resumption of development of hypobiotic worms) with peak of infection in July. The decline in FEC in the following months may be due spontaneous occurrence of "self-cure" phenomenon following acquisition of fresh wave of infection from pasture and expulsion of old worms FECs (Swarnkar *et al.* 2008). The non significant variation among different breeds during April could be due to similar rate of resumption of development of hypobiotic larvae (Singh and Swarnkar 2014) while in July and September could be attributed to the effects of self-cure phenomenon (Allonby and Urquhart 1973) and anthelmintic intervention, respectively. Thus, based on these findings and to harvest the benefits of "self-cure" phenomenon in strongyle worms, it is not necessary to drench the flocks on first rise in FECs at the end of summer season. Further adoption of this practice will be useful in increasing the size of refugia and maintenance of anthelmintic efficacy for longer period.

Parasitic gastroenteritis in sheep in Rajasthan

Nutritional status vis-a-vis submandibular oedema: In field flocks of Rajasthan, the occurrence of submandibular oedema without visible anaemia in 20-30% of sheep during the period from late November to February is a constant feature. Due to symptoms of oedema (bottle jaw) sheep farmers as well as chemists and technocrate give emphasis on use of anthelmintic keeping in mind that this menace is due to worms. However, the systematic study at CSWRI, Avikanagar reflected different scienario. In brief with respect to nutritional status, the availabilty of grazing material and seasonal influences indicated that sheep flocks are under low plane of nutrition during summer and maintained on fodder from top feed. With the onset of monsoon, though there is enough grazing material on surface but because of higher moisture content in fodder, the situation of low plane of nutrition remained as such. In succeeding months majority of sheep became pregnant and in late gestation/early lactation stage (November), the animal could not meet required amount of protein (lactational stress, prolonged low plane of nutrition) resulting in hypoproteinemia and occurrence of bottle jaw. The role of nutritional stress is further supported by parasitological observations that during this period the FECs were quite low (<200 epg) and pasture infectivity was almost nil (Swarnkar *et al.* 2008). Thus to mitigate the problem of submandibular oedema during

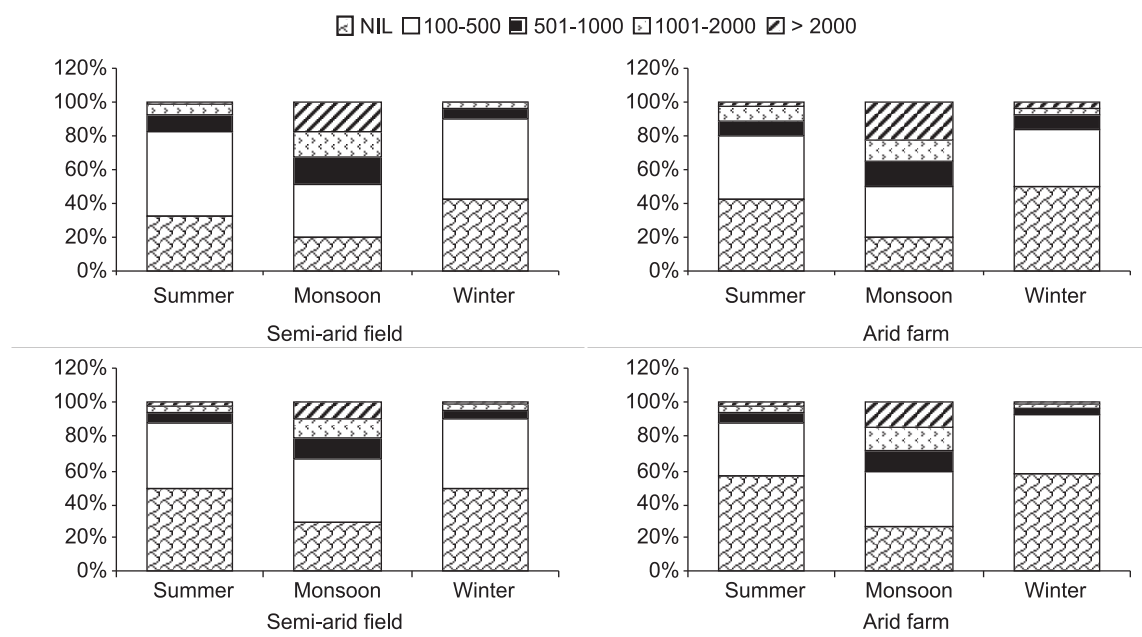


Fig. 6. Seasonal extent of over-dispersion in FECs in sheep flocks naturally infected with strongyle worms (predominantly *Haemonchus contortus*).

winter in sheep, emphasis must be diverted from anthelmintic intervention to nutritional (high protein) intervention.

Over dispersion in faecal egg counts: With the general agreement of advisers, sheep farmers traditionally treat all animals in a flock and tend to increase the frequency of treatments to prevent a recurrence. However in flocks, over-dispersion in FEC is the rule rather than the exception (Barger 1985). GI parasite populations in small ruminants are highly aggregated and over-dispersed, with around 80% of the worms found in only 20-30% of the host, whilst the vast majority of host posses low worm burden (Hoste *et al.* 2002). Thus a smaller proportion of highly susceptible animals is primarily responsible for contaminating the pasture for all other animals. The requirement for treatment is a reflection of the genetic basis of host variation in either innate or acquired resistance to parasites or resilience (Bisset *et al.* 2001).

The epidemiological studies in sheep flocks of Rajasthan revealed that even during favourable season (July-September) around 20-30% and 50% of sheep in field and farm conditions, respectively had FECs to the tune of >1000 epg (Fig. 6). Otherwise in rest of seasons, majority of animals had either <200 epg or free of infection (Swarnkar *et al.* 2008). Further, Singh and Swarnkar (2014) observed that around 40 and 30% of animals had intensity to the tune of >1000 epg during July to October in all the breeds maintained at CSWRI, Avikanagar and SBF, Fatehpur, respectively. Among stationary flocks in field, the monthly profile of over-dispersion in FECs revealed that proportion of animals having >1000 epg varied from nil (December to March) to 31.1% (August). In migratory flocks the pattern was almost similar but compared to stationary flocks, relatively higher proportion of animals were found to posses

>1000 epg during September-October (Swarnkar and Singh 2012a).

Assumption like that each host is infected with the same number of worms, is not a criterion for en-mass anthelmintic intervention. In recent times, it has been recognized that the phenomenon of parasite over-dispersion could be put to good use if those animals suffering from level of infection sufficient to cause considerable production loss or health effects can be identified and treated individually (Singh and Swarnkar 2011). This phenomenon can be used in form of targeted selective treatment (TST) and for breeding for resistance / resilience to parasites ultimately with the aim to increase the size of *refugia*, maintain anthelmintic efficacy and cost-effective worm management (Singh and Swarnkar 2007, 2008).

Lambing pattern and source of infection: The usual composition of a flock at given time indicated a ratio of around 77: 23 for adult: lambs (Swarnkar *et al.* 2008). It is common practice in the fields that whenever farmer implements, anthelmintic intervention in flock, all the animals (irrespective of age) were given anthelmintics. These practices resulted in unnecessary use of around 30% of anthelmintics in flock. Though lambing in flocks occurred throughout the year but majority of sheep (80-90%) lambed from September/October to November/December. The young lambs are reared separately in corrals and not allowed for grazing with their dam in field. In practice, the young ones are mixed with adult flock for grazing after age of 2.0-2.5 months. Similarly in farm flocks, where lambing is concentrated from late December to February, the lambs were allowed to graze on pasture from May onward. In Rajasthan, higher pasture larval burden (PLB) was usually observed during monsoon (July to September). A small peak in PLB during February is attributed to favourable

environmental as well as resumption of hypobiotic worms and increased contamination of pasture by faeces from ewes in lambing.

Age is an important factor in the onset of infection in host body (Magona and Musisi 2002) and several studies demonstrated significant difference among different age groups of small ruminants in relation to the prevalence and intensity of *H. contortus* infection (Good *et al.* 2006, Nuruzzaman *et al.* 2012, Tesfaheywet 2012). The higher intensity of infection in younger animals is because of their low resistance or greater susceptibility due to the fact that these animals have not been exposed earlier to the infection. It was found that younger animals (up to 1 yr of age) had significantly ($P < 0.001$) higher FECs and mean monthly FEC ranged from <10 epg in July to >4000 epg in September (Singh and Swarnkar 2012b, Swarnkar *et al.* 2014). It was obvious that spring-born lambs exposed to naturally contaminated pasture and got opportunity to pick up infection during late June-July depending on onset of monsoon.

Thus, it can be postulated that in semi-arid conditions of Rajasthan, young sheep (born during spring season) of marketable age (3-6 months old) could be raised without anthelmintics till July. Further for remaining young ones in flocks, infection of GI nematodes could be effectively managed by a single anthelmintic intervention during mid monsoon (Singh and Swarnkar 2012b). The interaction between pasture infectivity, grazing / rearing practices and host's infectivity exhibited that pasture contaminated by the adult sheep during monsoon was the main source of infection for young sheep during July-August. Under such circumstances, provision of grazing of young lambs during monsoon on summer rested pasture could be of immense utility in keeping low level of infection in young ones. In this way these young sheep could be raised without anthelmintics till next wormy season.

Control of parasitic gastroenteritis in sheep in rajasthan

Refugia: One approach to preserve the anthelmintic efficacy is to maintain parasite populations in *refugia* (van Wyk 2001, Soulsby 2007). In the case of anthelmintic resistance the population in *refugia* can simply be defined as a population that is either unexposed to or, in certain circumstances, unaffected by an anthelmintic. Initially anthelmintic resistance management strategies were not specifically directed towards maintaining *refugia* but understandably, at a time when parasitism appeared to be an omnipresent threat, tended to be largely concerned with achieving effective control with fewer treatments (Dash 1986), ways of maximising and extending anthelmintic efficacy (Hennessy *et al.* 1991, Sanyal *et al.* 2003, Singh *et al.* 1999b, Swarnkar *et al.* 1998b) and maintaining biosecurity (Dobson *et al.* 2001). Now, attention has been given to *refugia* in an effort to maintain susceptibility within the suprapopulation (van Wyk *et al.* 2002, Leathwick *et al.* 2009).

Sources of refugia: The infrapopulations in untreated

hosts that provide *refugia* is refractory (but not resistant, e.g. histotropic larvae) to a particular drug treatment (Fleming *et al.* 2006). In temperate areas, the majority (up to 95%) of the parasite population (Barnes *et al.* 1988) is usually on pasture and provides a relatively large reservoir of susceptibility while in tropical areas, this may not always be the case, since the extreme heat desiccates the free living worm stages on pasture within four weeks (Barger 1994). In some cases, stage specific differences in susceptibility to an antiparasitic compound that are not attributable to resistance may provide some *refugia* even in treated animals. For example, the immature stages of some *T. circumcincta* populations are refractory to levamisole treatment (Grimshaw *et al.* 1996) and under these circumstances levamisole treatments may inadvertently maintain *refugia*. In contrast treatments with the macrocyclic lactones, which have efficacies approaching 100% against all developmental stages, result in negligible levels of *refugia*. Where environmental conditions promote the continual survival of larvae on pasture, a substantial pool of larvae in *refugia* is available on the farm.

Approaches to maintain refugia: All the three components of host-parasite-environment triad plays crucial role in maintaining the quantum of *refugia*.

Host based: These include reducing the number of treatments by targeting them effectively and/or selectively. Whenever anthelmintics are used, it is important to consider not only the impact on the infrapopulation but also what is happening at that time to the free living stages. For example, anthelmintic treatments that are administered when the suprapopulation size is drastically reduced (during dry periods, grazing on reseeded pastures), pose a considerable risk with regard to the selection of resistance. An understanding of this phenomenon has led to a move away from summer treatments in the winter rainfall areas of Australia (Besier and Love 2003) and recommendations not to dose animals onto clean grazing (Abbott *et al.* 2004). Sharing of community grazing area by groups of animals with different patterns of treatment may provide *refugia* and has been exploited in the management of resistance in Ethiopia (Sissay *et al.* 2006) and believed to be an important factor in accounting for the lack of resistance recorded in studies on the Greek mainland (Papadopoulos *et al.* 2001). The interaction between the immune status of the host and *refugia* may also account for variation in resistance and its prevalence in different ruminant species (Silvestre *et al.* 2002). Resilient animals continue to perform whilst under parasite challenge and therefore require less anthelmintic treatments than non-resilient animals (Bisset *et al.* 2001). The incorporation of resilient animals into flocks could also be used to manage *refugia* by providing untreated populations.

Parasite based: These includes the frequency of the resistant alleles in the parasite population, the biotic potential of the parasite and the longevity of both the supra and infrapopulations. The frequency of resistant genes influences the rate at which homozygous resistant parasites

appear in the population. If the proportion of resistance genes is high, then there is an increased probability that heterozygotes will have the opportunity to mate and produce homozygous resistant offspring. The degree of biotic potential of a parasite species determines the number of individuals of that species required to provide a given level of *refugia*. For example, species with high biotic potential, e.g. *H. contortus*, can provide a high degree of pasture contamination from relatively few individuals. Thus an effective *refugia* can, assuming successful completion of the lifecycle, be maintained by leaving a relatively small proportion of the host population unexposed to treatment. In other species with lower biotic potential, e.g. *T. circumcincta*, a greater proportion of the host population would need to be left unexposed to treatment to provide the same level of *refugia*.

A study at CSWRI, Avikanagar on the seasonal variation in different genotypes of *H. contortus* (w.r.t. BZ-resistance) showed annual frequency of 72.5% for homozygous resistant (rr) adult male *H. contortus*. Sheep were found to harbour more number of BZ-susceptible worms during monsoon and winter compared to summer (Swarnkar *et al.* 2006). The seasonal profile of genotypic frequency (w.r.t. BZ-resistance) among L₃ of *H. contortus* exhibited that in semi-arid farm prior to strategic anthelmintic intervention, the proportion of rr genotype in gene pool of larvae was >90% in host (up to September). Following deworming in mid-September the proportion of rr genotype was 40.0%. In succeeding unfavourable months with minimal chances of re-infection, the proportion of rr genotype in suprapopulation returned to previous level (>95%). In arid farm monthly frequency of rr genotype ranged from 40.0% in August to 100.0% in July.

Like-wise in field flocks, the frequency of rr genotype of *H. contortus* larvae was 97.58, 88.57 and 96.43%, respectively during summer, monsoon and winter season in semi-arid region. It was observed that in pre-drench gene pool the frequency of rr genotype was 92.5% which decreased to 75.0% in October indicating that smaller proportion of susceptible genotypes able to disseminate in later half of monsoon and dilute the gene population on *refugia*. Similarly in arid region, the proportion of rr genotype of *H. contortus* larvae found to contribute to gene pool of suprapopulation on pasture was 85.62, 86.54 and 92.13%, respectively during summer, monsoon and winter season. Similar to semi-arid region, it has been observed that in pre-drench gene pool the frequency of rr genotype was around 90.0% which reduced to 40.0% in October but reached to pre-drench level thereafter. Thus, deworming in later half of monsoon is helpful in increasing the efficacy of anthelmintics by increasing the size of *refugia*. Rising trend in prevalence of rr genotype from November onwards might reflect the role of migration and unplanned grazing and anthelmintic use in field flocks in maintaining the high level of BZ-resistance.

Climate and management based: Environmental conditions and management practices that influence the

development of eggs and larvae on pasture can also have impact upon the maintenance of *refugia*. For example, control programs that leave relatively low or no parasites in *refugia*, i.e. spring treatments against a parasite species that overwinters poorly or dose and move to clean pasture, select strongly for resistance (Abbott *et al.* 2004).

Exploitation of refugia concept in worm management: The concept of *refugia* can be applied to slow the development of resistance through the use of approaches such as dilution of resistant with susceptible parasites when the proportion of resistance alleles is high, and targeted and selectively targeted treatments when resistant alleles are less common (Gaba *et al.* 2006).

Community dilution strategy: Once anthelmintic resistance has been identified to a particular drug on a farm, it may be possible to substitute the resistant parasite community for a susceptible one. To date, several studies have been conducted to examine the feasibility of replacing BZ resistant *H. contortus* (van Wyk and van Schalkwyk 1990) or *T. circumcincta* (Moussavou-Boussougou *et al.* 2007) or multi-drug resistant nematodes (Sissay *et al.* 2006) with susceptible nematodes on pasture. Singh and Swarnkar (2012c) observed that inadvertently community dilution strategy helped in reversion to susceptibility for BZ at Sheep Breeding Farm, Fatehpur (Rajasthan). In this farm BZ resistance was first detected in 1998 with nil efficacy for BZ anthelmintics (Swarnkar *et al.* 1999). On subsequent years there was gradual rise in % efficacy of BZ whenever examined and with marginal rise in BZ susceptible alleles (Swarnkar *et al.* 2004). On exploration the causes of these findings it was found that unwanted introduction of field animals infected with BZ susceptible strains of *H. contortus* (Anon 2004) for grazing on pasture area of farm led to dilution of resistant population in *refugia* with resultant increase in anthelmintic efficacy at farm. On molecular study it was observed that community dilution strategy for reversion of susceptibility to BZ in *H. contortus* could be feasible in farm condition. Under prevailing managerial and grazing practices in field flocks, the variation in genotypic frequency could not be recorded. The period from September to November in semi-arid and from June to February in arid Rajasthan was found appropriate in increasing the frequency of BZ-susceptible alleles in the *refugia* (Swarnkar and Singh 2012b; Swarnkar *et al.* 2012).

Targeted treatment (TT): It means whole flock treatments given at the most appropriate times bearing in mind the need to maintain *refugia*. These treatments differ from strategic treatments which are generally given prophylactically on the basis of epidemiology in a given area and are used to protect animals and prevent disease over a substantial period. Effective targeting should also lead to an increased interval between treatments, allowing susceptible genotypes a better opportunity to establish on pasture and so reduce the risk of heterozygotes mating and producing homozygous resistant offspring. Examples of the use of TT approach include studies conducted in Western Australia (Besier and Love 2003) and Italy (Cringoli *et al.*

2008) where treatments were stopped during summer months when few parasites were present on pasture and given instead at other times when more parasites were present in *refugia*.

Targeted selective treatment (TST): TST particularly aims at treating only those animals unable to withstand current worm challenges, is not only exceptionally affordable in relation to other conventional control programmes, but will also help to delay selection for anthelmintic resistance (Sanyal 2009, van Wyk *et al.* 2006), reduced selection pressure, lower drug residues in animal products and lower costs of worm management. It exploited both epidemiologically appropriate treatment times and involved selective treatment of only those animals that will most benefit from treatment, leaving rest of the flock untreated. TST is directed towards those animals that are susceptible or that most contaminate pasture and this requires the ability to identify these individuals within a flock (Jackson and Coop 2000). Particularly, in the population of *H. contortus* to maintain the susceptibility of anthelmintics by reducing the selection pressure and allowing the maintenance of susceptible worms in *refugia*, the FAMACHA method has been developed (van Wyk and Bath 2002). This method consists of an animal's conjunctiva, which may vary by five categories of colour that correlate with micro-haematocrit measurements. A color chart based on ocular mucous membrane, microhaematocrit and intensity of infection in sheep was developed and tested at CSWRI, Avikanagar (Singh and Swarnkar 2012a). On screening of flocks for conjunctiva color, under natural GIN infection (predominantly *H. contortus*), the monthly frequency distribution showed an overall proportion of visually anaemic sheep (category 4+5) to the tune of 2.33% with maximum (2.88%) during monsoon followed by 2.33% during winter and minimum (1.32%) during spring season (Table 2). The proportion of

sheep drenched with anthelmintic in TST approach ranged from 8.65 (2012-13) to 29.31% (2008-09) with an average of 16.23% compared to >100% drenching in conventional treatment approach. The comparative performance of sheep flocks with conventional and TST approach of worm management exhibited significant reduction in cost of worm management (about 90%) without hampering the flock productivity (Singh and Swarnkar 2012a).

It was found that application of TST is feasible and effective not only in managing the haemonchosis but also helped in increasing the size of *refugia* which ultimately resulted into both maintenance of drug efficacy against parasites and sizeable reduction in the cost of worm management in sheep flocks. The main disadvantages are the difficulty and time spent on selecting animals in need of treatment and the possibility of lower production (Cabaret 2008).

Breeding for increasing resistance / resilience to GINs: Differences in the level of GI infections between breeds have been documented both in sheep (Gray 1997). The largest source of genetic variation in resistance is between sheep within a flock, rather than between different flocks (Kumar *et al.* 2006). In most studies, FEC was the main phenotypic marker used for selection of the responding animals (Hunt *et al.* 2008). The heritability of resistance to GIN infection in sheep, as measured by FEC varied from 0.01 to 0.50. Using FEC as phenotypic marker for within breed selection of resistant and / or susceptible animals at CSWRI, Avikanagar it was observed that this trait is low to moderately heritable (Singh *et al.* 1999a, 2009, Swarnkar *et al.* 2009, Prince *et al.* 2010). The profile of intensity of strongyle infection in divergent lines (resistant "R" and susceptible "S") over the years exhibited that animals of R-line had lower monthly FECs compared to their counterparts in S-line. The animals of S-line required strategic as well as tactical anthelmintic intervention while

Table 2. Frequency (%) distribution for different categories of conjunctiva color in sheep

Factor	No. of observations	TST categories				
		1	2	3	4	5
Overall	24403	4.09	24.94	68.64	2.07	0.26
Season						
Monsoon	10094	4.18	24.58	68.36	2.48	0.40
Winter	7856	4.05	24.07	69.35	2.13	0.20
Spring	5453	4.00	26.87	67.82	1.25	0.07
Month						
July	3201	2.91	27.21	67.38	2.16	0.34
August	3357	5.03	23.01	69.33	2.29	0.34
September	3356	4.50	23.71	68.30	2.98	0.51
October	3398	4.09	23.81	69.63	2.21	0.26
November	2326	4.51	24.29	68.97	2.06	0.17
December	2132	3.47	24.25	70.08	2.06	0.14
January	1570	3.69	23.89	71.40	1.02	0.00
February	1905	4.25	29.29	65.36	1.00	0.10
March	1978	3.99	26.90	67.34	1.67	0.10

Monsoon: July-September; Winter: October-December; Spring: January-March.

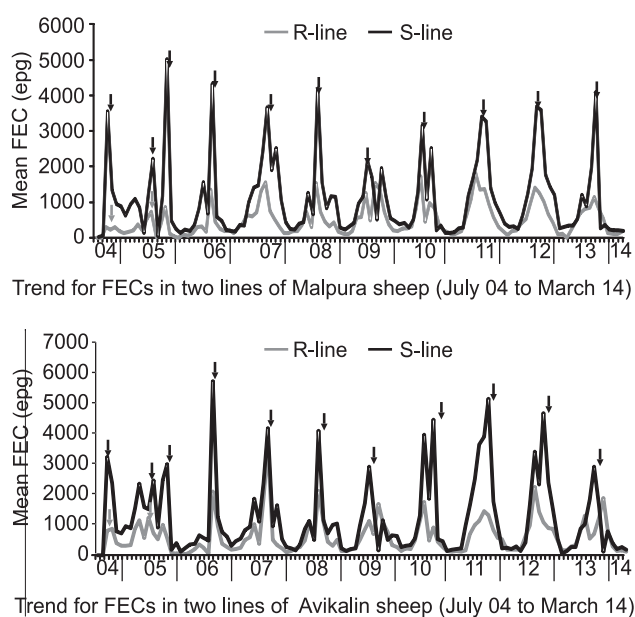


Fig. 7. Monthly intensity of strongyle infection in two divergent lines of sheep (arrow in red colour indicates anthelmintic intervention, red in S-line and green in R-line).

animals of R-line were maintained without any anthelmintic intervention (Fig. 7).

Grazing practices and infectivity pattern: The aim of grazing management is to have vulnerable sheep exposed to fewer larvae on pasture which not only is supposed to reduce drench frequency but also provided better nutrition at the same time, thus allow sheep to better deal with parasites. It is stated that “Drenching is not a substitute for good feeding” and “There is no better anthelmintic than good quality green grass”. Grazing management decisions should aim at providing these, or if unachievable, high quality supplements should be fed. The success of the strategy depends upon the relation between the annual cycle of the number of worm larvae on the pasture and when the grazing management practice is applied. It is most successful if applied when larval numbers are at low levels and this is determined by the season. If PLB is high during winter then better to target the summer for reducing larvae on the pasture (in trichostrongylosis) while, in haemonchosis prone areas where high PLB occurred during spring and monsoon, efforts must be made to limit contamination of pasture during autumn and spring. Moving the animals on safe pasture after anthelmintic treatment has been an important strategy adopted since long for worm control. This practice enhanced the selection of resistant alleles in parasitic population because the next generation of parasite constituted mainly the progeny of the worms which survived the treatment. If the pasture is highly infective and sheep are highly susceptible and kept on same pasture after deworming, re-infection will occur quickly and selection for resistance is minimised. Similarly, control programmes that involved little or no anthelmintic treatment such as the cattle grazed on the pasture grazed by the sheep in previous year, are ideal for maintaining anthelmintic

susceptibility.

In Rajasthan, the grazing system for livestock as followed by farmers is rotational in nature depending upon the availability of fodder. It has been observed that farmers put their animals on community grazing land / forest with the onset of monsoon where animals are drenched during mid-monsoon and continued on the same up to October. After harvesting of *kharif* crop the flocks are moved on such field to utilize crop stubbles for a period of one month. From November onward the flocks were again moved to community grazing land, forest or maintained on top feed with intermittent grazing on crop stubbles after *rabi* harvesting. Such grazing management of field flocks was found to be the reason behind relatively lower intensity of infection in them compared to farm flocks.

Grazing behaviour / alternate grazing system: As the highest concentrations of nematode larvae are found in the lowest strata of the pasture, it has been suggested that a well planned grazing rotation which makes it possible to keep a bank of fresh pasture ahead of flocks may reduce their rate of intake of worm larvae. The alternate grazing for parasite control is based on different age groups of the same species (taking advantage of higher resistance in older animals) or different species (little cross infectivity between species and reduced susceptibility of different host species) grazing the pasture in sequence (Singh and Swarnkar 2005). In area where *T. axei* is not a major concern, alteration between small ruminants and cattle would be successful. In *H. contortus* predominant area, though the parasite infects cattle but fail to cause any disease, thus small ruminants and cattle alteration works. However in environment where *H. placei* infect cattle great caution should be exercised if their pastures are used for grazing by small ruminants, as this species is pathogenic in all hosts. In this approach older animals or a different species of livestock will act as a vacuum cleaner thereby reducing the number of infective larvae on pasture. It has been observed that intensity of GIN in farmer's flock was low compared to farm flocks. One of the reasons behind this finding is that in rural area farmers graze all types of animals on same community grazing land in contrast to mono-specific grazing in organized farms.

Pasture resting and infectivity of GI nematodes in sheep: It consists of preventing the animals from grazing in the same field or paddock. Resting of pasture allow grasses in a more vegetative stage and tall enough to provide better nutrition to keep the animal healthier and strengthening their immune system to prevent adult worms from producing eggs. In cooler temperatures, some of these larvae can live for up to 6-8 months, while in warmer temperatures survival may be only 2-3 months. The study conducted in semi-arid Rajasthan (using tracer lambs) revealed that sheep grazed during monsoon on spring contaminated-summer ungrazed pasture had very low FEC and worm count compared to those placed on continuously grazed contaminated pasture. The pasture larval burden was higher in general pasture than summer ungrazed pasture. Thus, resting the

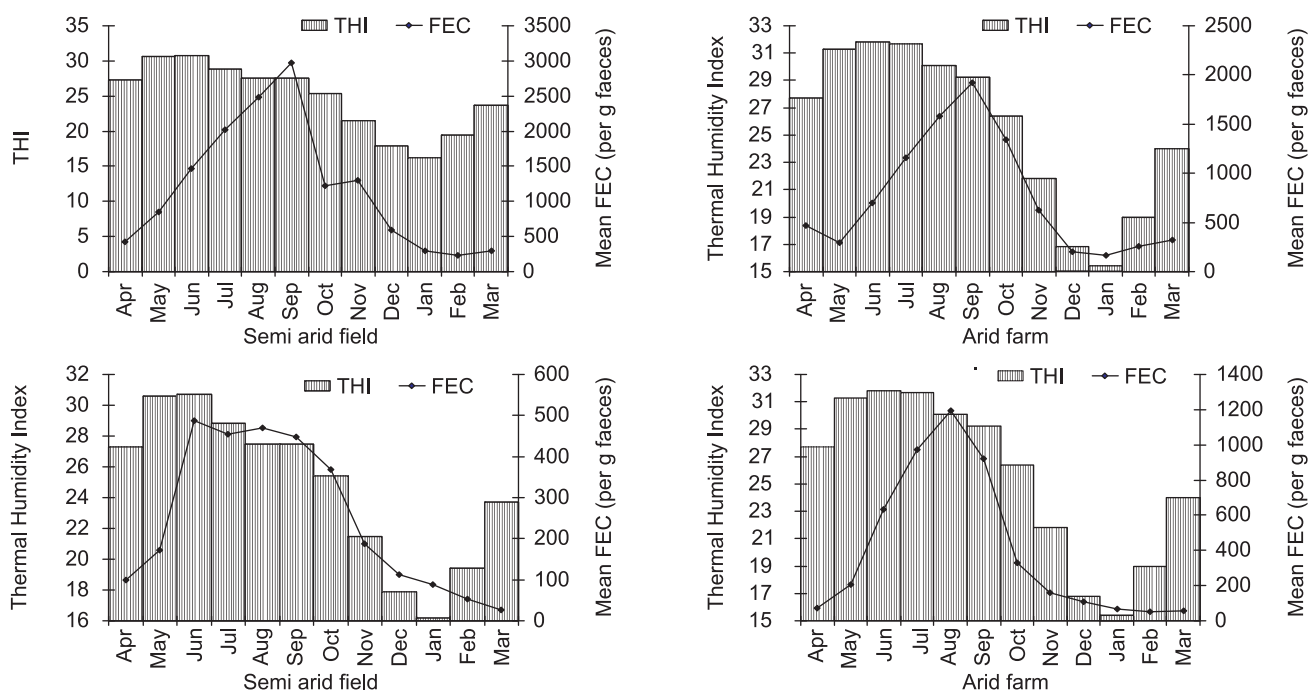


Fig. 8. Interaction between monthly THI and FEC/PLB.

contaminated pasture during summer was found to effectively control the pasture larval burden (Swarnkar *et al.* 2008).

Thermal humidity index (THI) and regulation of strongyle worms in sheep of Rajasthan: Marai *et al.* (2007) classified stress conditions for sheep as no heat stress (THI <22.2), moderate heat stress (THI 22.2 to <23.3), severe heat stress (THI 23.3 to <25.6) and extreme severe heat stress (THI > 25.6). The overall monthly THI varied from 16.2 ± 0.2 (January) to 30.7 ± 0.2 (June) and from 15.4 ± 0.3 (January) to 31.8 ± 0.1 (June) in semi-arid and arid region, respectively. The monthly THI values indicated that period from November to February is non-stressful for sheep of Rajasthan, thereby low intensity of infection in host during these months (Fig. 8).

The animals were found to be under conditions of extreme severe heat stress from April to October, intensity of infection in sheep started rising from May onward and reached to peak in the month of September. Relatively lower magnitude of infection during early period of heat stress (April-June) was attributed to non availability of infective larvae on pasture compared to late phase of high THI. In the late phase (July-September), THI and other conditions were found suitable for translation of exogenous stages. The higher pasture infectivity as well as expected nutritional stress along with heat stress resulted in higher intensity of infection in sheep during the period from June-July to September-October.

The ability to predict the timing and magnitude of infection level in host and on pasture to plan grazing and worm control strategies are important requirement of preventing losses caused by gastrointestinal nematodes in sheep. Since, last five decades time-to-time introduction

of efficacious chemotherapeutics put the interest on role of biology of free-living stages of parasites in corner but development of anthelmintic resistance now forces us to resurrect this discipline and give full attention to it in formulation of strategies for worm management. Climatic consideration in combination with grazing history and practices can be taken into account in evaluating expected levels of *refugia* and thus treatments can be avoided at times when *refugia* are likely to be small. Anthelmintic treatment of livestock for the purpose of controlling strongyle parasites should be restricted to the active parasite transmission season. Thus, present strategies of frequent deworming as practiced throughout the country should be avoided. In ever-changing scenario of dynamics of parasite epidemiology more attention and research is needed for a thorough quantitative discipline of strongyle larval bionomics and a better understanding of their basic epidemiology on regional basis.

REFERENCES

- Abbott K A, Taylor M A and Stubbings L A. 2004. Anthelmintic resistance management in sheep. *Veterinary Record* **154**: 735–36.
- Allonby E W. and Urquhart G M. 1973. Self-cure of *Haemonchus contortus* infections under field conditions. *Parasitology* **66**: 43–53.
- Anon. 2004. *Annual Progress Report: All India Network Program on Gastrointestinal Parasitism*, CSWRI, Avikanagar, pp. 1–45.
- Barger I A. 1985. The statistical distribution of trichostrongylid nematodes in grazing lambs. *International Journal for Parasitology* **15**: 645–49.
- Barger I A. 1994. Rotational grazing for control of gastrointestinal nematodes of goats in a wet tropical environment. *Veterinary Parasitology* **53**: 109–16.

- Barnes E H, Dobson R J, Donald A D and Waller P J. 1988. Predicting populations of *Trichostrongylus colubriformis* infective larvae on pasture from meteorological data. *International Journal for Parasitology* **18**: 767–74.
- Besier R B and Love S C J. 2003. Anthelmintic resistance in sheep nematodes in Australia : the need for new approaches. *Australian Journal of Experimental Agriculture* **43**: 1383–91.
- Bisset S A, Morris C A, McEwan J C and Vlassoff A. 2001. Breeding sheep in New Zealand that are less reliant on anthelmintics to maintain health and productivity. *New Zealand Veterinary Journal* **9**: 236–46.
- Blitz N M and Gibbs H C. 1972. Studies on the arrested development of *Haemonchus contortus* in sheep. 2. Termination of arrested development and the spring rise phenomenon. *International Journal for Parasitology* **2**: 13–22.
- Cabaret J. 2008. Pro and cons of targeted selective treatment against digestive tract strongyle of ruminants. *Parasite* **15**: 506–09.
- Cringoli G, Veneziano V, Jackson F, Vercruysse J, Greer A W, Fedele V, Mezzino L and Rinaldi L. 2008. Effects of targeted anthelmintic treatments on the milk production of dairy cattle naturally infected by gastrointestinal strongyles. *Veterinary Parasitology* **156**: 340–45.
- Crofton H D. 1948. The ecology of immature phases of *Trichostrongylus* nematodes: 1. The vertical distribution of infective larvae of *Trichostrongylus retortaeformis* in relation to their habit. *Parasitology* **39**: 17–25.
- Dash K M. 1986. Control of helminthosis in lambs by strategic treatment with closantel and broad-spectrum anthelmintics. *Australian Veterinary Journal* **63**: 4–7.
- Dhar D N, Sharma R L and Bansal G C. 1982. Gastrointestinal nematodes in sheep in Kashmir. *Veterinary Parasitology* **11**: 271–77.
- Dobson R J, Besier R B, Barnes E H, Love S C J, Vizard A, Bell K and Le Jambre L F. 2001. Principles for the use of macrocyclic lactones to minimize selection for resistance. *Australian Veterinary Journal* **79**: 756–61.
- Fakae B B. 1990. Seasonal changes and hypobiosis in *Haemonchus contortus* infection in the West African Dwarf sheep and goats in the Nigerian Derived Savanna. *Veterinary Parasitology* **36**: 123–130.
- Fleming S A, Craig T, Kaplan R M, Miller J E, Navarre C and Rings M. 2006. Anthelmintic resistance of gastrointestinal parasites in small ruminants. *Journal of Veterinary Internal Medicine* **20**: 435–44.
- Gaba S, Cabaret J, Ginot V and Silvestre A. 2006. The early drug selection of nematodes to anthelmintics: stochastic transmission and population in refuge. *Parasitology* **133**: 345–56.
- Good B, Hanrahan J P, Crowley B A and Mulcahy G. 2006. Texel sheep are more resistant to natural nematode challenge than Suffolk sheep based on faecal egg count and nematode burden. *Veterinary Parasitology* **136**: 317–27.
- Gordon H M. 1948. The epidemiology of parasitic diseases, with special reference to studies with nematode parasites of sheep. *Australian Veterinary Journal* **24**: 17–45.
- Gordon H M. 1953. The epidemiology of helminthosis in sheep in winter rainfall regions of Australia. I. preliminary observations. *Australian Veterinary Journal* **29**: 337–48.
- Gray G D. 1997. The use of genetically resistant sheep to control nematode parasitism. *Veterinary Parasitology* **72**: 345–57.
- Grimshaw W T, Hong C and Hunt K R. 1996. Potential for misinterpretation of the faecal egg count reduction test for levamisole resistance in gastrointestinal nematodes of sheep. *Veterinary Parasitology* **62**: 267–73.
- Gupta R P, Ruprah N S and Yadav C L. 1986. Some observations on the spring-rise phenomenon in sheep of Haryana (India). *Indian Veterinary Journal* **63**: 449–53.
- Gupta R P, Yadav C L and Choudhri S S. 1987. Epidemiology of gastrointestinal nematodes of sheep and goat in Haryana. India. *Veterinary Parasitology* **24**: 117–27.
- Hennessy D R, Ali D N and Steel J W. 1991. The pharmacodynamic relationship of oxfendazole with feed intake in sheep. *Acta Veterinaria Scandinavica Suppl.* **87**: 389–91.
- Hoste H, Lefrileux Y and Pommaret A. 2002. Comparison of selective and systematic treatments to control nematode infections of the digestive tract in dairy goats. *Veterinary Parasitology* **106**: 345–55.
- Hunt P W, McEwan J C and Miller J E. 2008. Future perspectives for the implementation of genetic markers for parasite resistance in sheep. *Tropical Biomed* **25**: 18–33.
- Jackson F and Coop R L. 2000. The development of anthelmintic resistance in sheep nematodes. *Parasitology* **120**: S95–S107.
- Kumar S, Swarnkar C P, Singh D, Kolte A P and Singh V K. 2006. Genetic resistance to parasitic nematodes – A review. *Indian Journal of Small Ruminants* **12**: 131–45.
- Leathwick D M, Hosking B C, Bisset S A and McKay C H. 2009. Managing anthelmintic resistance: is it feasible in New Zealand to delay the emergence of resistance to a new anthelmintic class? *New Zealand Veterinary Journal* **57**: 181–92.
- Magona J W and Musisi G. 2002. Influence of age, grazing system, season and agroclimatic zone on the prevalence and intensity of gastrointestinal strongylosis in Ugandan goats. *Small Ruminant Research* **44**: 187–92.
- Marai I F M, El-Darawany A A, Fadiel A and Abdel-Hafez M A M. 2007. Physiological traits as affected by heat stress in sheep- A review. *Small Ruminant Research* **71**: 1–12.
- Moussavou-Boussougou M N, Silvestre A, Cortet J, Sauve C and Cabaret J. 2007. Substitution of benzimidazole-resistant nematodes for susceptible nematodes in grazing lambs. *Parasitology* **134**: 553–60.
- Nuruzzaman M, Haque M H, Sarker S and Begum N. 2012. Abomasal nematodes in goats slaughtered at different abattoir of Thakurgaon district, Bangladesh. *Journal of Scientific Research* **4**: 491–97.
- O'Connor L J, Walkden-Brown S W and Khan L P. 2006. Ecology of the free-living stages of major trichostrongylid parasites of sheep. *Veterinary Parasitology* **142**: 1–15.
- O'Sullivan B M and Donald A D. 1970. A field study of nematode parasite populations in the lactating ewes. *Parasitology* **61**: 301–15.
- Papadopoulos E, Himonas C and Coles G C. 2001. Draught and flock isolation may enhance the development of anthelmintic resistance in nematodes. *Veterinary Parasitology* **97**: 253–59.
- Prince L L L, Gowane G R, Swarnkar C P, Singh D and Arora A L. 2010. Estimates of genetic parameters for faecal egg count of *Haemonchus contortus* infection and relationship with growth traits in Avikalin sheep. *Tropical Animal Health and Production* **42**: 785–91.
- Rocha R A, Rocha G P, Bricarello P A and Amarante A F. 2008. Recovery of *Trichostrongylus colubriformis* infective larvae from three grass species contaminated in summer. *Revista Brasileira de Parasitologia Veterinária* **17**: 227–34.
- Sanyal P K. 1988a. Effect of Periparturient anthelmintic dosing of ewes in south sub temperate climate. *Indian Veterinary Medical Journal* **12**: 182–83.

- Sanyal P K. 1988b. Preliminary studies on hypobiosis-a diapause phenomenon of *Haemonchus contortus*. *Indian Veterinary Medical Journal* **12**: 111–14.
- Sanyal P K. 1989a. Bionomics of preparasitic stages of ovine strongyles in faeces and on pasture in subtemperate Tamil Nadu. *Indian Journal of Animal Sciences* **59**: 1493–97.
- Sanyal P K. 1989b. Hypobiosis in *Haemonchus contortus* in south Indian sub temperate climate. *Indian Journal of Animal Sciences* **59**: 1224–27.
- Sanyal P K. 1996. Gastrointestinal parasites and small ruminant production in India. *Australian Centre for International Agricultural Research Proceedings No. 74 on Sustainable Parasite Control in Small Ruminants*. ACIAR, Canberra, Australia, pp. 109–112.
- Sanyal P K. 1998. Integrated parasite management in ruminants in India: A concept note. *Biological control of Gastro Intestinal Parasites of Ruminants using Predacious Fungi*, FAO Animal Production and Health Paper 141, FAO, Rome, pp. 54–65.
- Sanyal P K, Swarnkar C P, Singh D, Khan F A and Bhagwan P S K. 2003. Sheep and albendazole model for a new approach on judicious use of anthelmintics in small ruminants. *Journal of Veterinary Parasitology* **17**: 15–19.
- Sanyal P K. 2009. Automated technology transfer for sustainable control of parasitic gastroenteritis in small ruminants: A review. *Indian Journal of Small Ruminants* **15**: 134–55.
- Silangwa S M and Todd A C. 1964. Vertical migration of trichostrongyle larvae in grasses. *Journal of Parasitology* **50**: 278–85.
- Silvestre A, Leignel V, Berrag B, Gasnier N, Humbert J F, Chartier C and Cabaret J. 2002. Sheep and goat nematode resistance to anthelmintics: pro and cons among breeding management factors. *Veterinary Research* **33**: 465–80.
- Singh D and Swarnkar C P. 2005. Epidemiology and pasture management for the control of ovine gastrointestinal nematodosis. In: *Proceedings of FAO Symposium on "Integrated Animal Parasite Management: From Academic Interest to Reality"* Durg, December 6–8, pp 23–33.
- Singh D and Swarnkar C P. 2007. Alternative methods of control of gastrointestinal nematodosis in small ruminants. *Small Ruminants Emerging Diseases Containment under WTO Regime*. pp. 269–303. (Eds) Vihan V S, Kumar Ashok, Gupta V K and Singh N P. Satish Serial Publishing House, Delhi.
- Singh D and Swarnkar C P. 2008. Role of refugia in management of anthelmintic resistance in nematodes of small ruminants: A review. *Indian Journal of Small Ruminants* **14**: 141–80.
- Singh D and Swarnkar C P. 2011. Epidemiology and management of gastrointestinal helminths in small ruminants – An Update. In: *Trends in Small Ruminant Production: Perspectives and Prospects*. pp 347–96. (Eds) Sahoo A, Sankhyan S K, Swarnkar C P, Shinde A K and Karim S A. Satish Serial Publishing House, Delhi.
- Singh D and Swarnkar C P. 2012a. Evaluation of targeted selective treatment strategy in sheep farm of Rajasthan. *Indian Journal of Animal Sciences* **82**: 679–86.
- Singh D and Swarnkar C P. 2012b. Epidemiology and management of gastrointestinal nematodes in young sheep at an organised farm in semi-arid Rajasthan. *Indian Journal of Small Ruminants* **18**: 220–24.
- Singh D and Swarnkar C P. 2012c. Worm management in Small Ruminants. In: *Integrated Research Approaches in Veterinary Parasitology* (Daya Shanker, Jitendra Tiwari, Amit K Jaiswal and Vikrant Sudan Eds.), DUVASU, Mathura, pp 75–94.
- Singh D and Swarnkar C P. 2013. Comparative impact of conventional and strategic worm management schemes in sheep flocks of arid Rajasthan. *Indian Journal of Animal Sciences* **83**: 1128–34.
- Singh D and Swarnkar C P. 2014. Influence of sheep breeds on the susceptibility to strongyle infection in Rajasthan. *Indian Journal of Animal Sciences* **84**: 120–26.
- Singh D, Swarnkar C P, Khan F A, Srivastava C P and Bhagwan P S K. 1997. Epidemiology of ovine gastrointestinal nematodes at an organized farm in Rajasthan, India. *Small Ruminant Research* **26**: 31–37.
- Singh D, Swarnkar C P, Khan F A, Jayasankar J and Bhagwan P S K. 1999a. Heritability of faecal egg counts in Avikalin sheep. *Indian Journal of Animal Science* **69**: 983–85.
- Singh D, Sanyal P K, Swarnkar C P, Khan F A and Bhagwan P S K. 1999b. Influence of diet type and pretreatment fasting on kinetics of albendazole in sheep. *Journal of Veterinary Parasitology* **23**: 229–40.
- Singh D, Swarnkar C P and Khan F A. 2002. Anthelmintic resistance in gastrointestinal nematodes of livestock in India. *Journal of Veterinary Parasitology* **16**: 115–30.
- Singh D, Swarnkar C P, Kumar Sushil, Prince L L L and Arora A L. 2009. Performance of Avikalin sheep selected for resistance to *Haemonchus contortus*. *Journal of Veterinary Parasitology* **23**: 23–27.
- Sissay M M, Asefa A, Uggle A and Waller P J. 2006. Anthelmintic resistance of nematode parasites of small ruminants in eastern Ethiopia: Exploitation of refugia to restore anthelmintic efficacy. *Veterinary Parasitology* **135**: 337–46.
- Soulsby E J L. 1982. *Helminths, Arthropods and Protozoa of Domesticated Animals*. 7th edn, p. 252. Bailliere and Tindall, London.
- Soulsby E J L. 2007. New concepts in strongyle control and anthelmintic resistance: the role of refugia. *Veterinary Journal* **174**: 6–7.
- Southcott W H, Major G W and Barger I A. 1976. Seasonal pasture contamination and availability of nematodes for grazing sheep. *Australian Journal of Agricultural Research* **27**: 277–89.
- Stewart D F. 1950. Studies on resistance of sheep to infestation with *Haemonchus contortus* and *Trichostrongylus* spp and on the immunological reactions of sheep exposed to infestations. IV. The antibody response to natural infestation in grazing sheep and the self-cure phenomenon. *Australian Journal of Agricultural Research* **1**: 427–39.
- Stewart D F. 1953. Studies on resistance of sheep to infestations with *Haemonchus contortus* and *Trichostrongylus* spp. and on the immunological reactions of sheep exposed to infestations. V. The nature of the self-cure phenomenon. *Australian Journal of Agricultural Research* **4**: 100–17.
- Stoll N R. 1929. Studies with the strongyloid nematode, *Haemonchus contortus*. I. Acquired resistance of hosts under natural reinfection conditions out-of-doors. *American Journal of Hygiene* **10**: 384–418.
- Stromberg B E. 1997. Environmental factors influencing transmission. *Veterinary Parasitology* **72**: 247–64.
- Swarnkar C P and Singh D. 2010a. Questionnaire Survey on sheep husbandry and worm management practices adopted by farmers in Rajasthan. *Indian Journal of Small Ruminants* **16**: 199–209.
- Swarnkar C P and Singh D. 2010b. Worm control practices, anthelmintic use and its implication on anthelmintic resistance in gastrointestinal nematodes of sheep in Rajasthan. *Indian Journal of Animal Sciences* **80**: 593–600.
- Swarnkar C P and Singh D. 2011. Role of bioclimatographs in

- forecasting of strongyle infection in Rajasthan. *Indian Journal of Animal Sciences* 81: 216–23.
- Swarnkar C P, Khan F A, Singh D, Sharma S R and Bhagwan P S K. 1998a. Some observations on periparturient rise in ewes at an organised farm. *Indian Veterinary Journal* 75: 781–84.
- Swarnkar C P, Singh D, Khan F A, Srivastava C P and Bhagwan P S K. 1997. Development and survival of *Haemonchus contortus* larvae on pasture under semi-arid conditions of Rajasthan. *Journal of Veterinary Parasitology* 11: 37–41.
- Swarnkar C P, Sanyal P K, Singh D, Khan F A and Bhagwan P S K. 1998b. Comparative disposition kinetics of albendazole in sheep following oral and intraruminal administration. *Veterinary Research Communications* 22: 545–51.
- Swarnkar C P, Singh D, Khan F A and Bhagwan P S K. 1999. Multiple anthelmintic resistance in *Haemonchus contortus* of sheep. *Indian Journal of Animal Sciences* 69: 547–49.
- Swarnkar C P, Singh D, Khan F A, Tiwari R and Dubey S C. 2004. Prevalence of anthelmintic resistance and seasonal variation in efficacy of anthelmintic in sheep. In: *XV National Congress of Indian Association for the Advancement of Veterinary Parasitology*, College of Veterinary and Animal Sciences, GBPUAT, Pantnagar, 25–27 October.
- Swarnkar C P, Singh D, Kumar S, Khan F A and Tiwari J. 2006. Investigations on the seasonal pattern of Strongyle infection in sheep and interaction between genotypes of *Haemonchus contortus* in refugia and benzimidazole resistance in Rajasthan. In: *XVII National Congress of Indian Association for the Advancement of Veterinary Parasitology*, Rajiv Gandhi College of Veterinary Sciences, Puducherry, 15–17 November.
- Swarnkar C P, Singh D, Krishna Lal and Khan F A. 2008. *Epidemiology and Management of Gastrointestinal Parasites of Sheep flocks in Rajasthan*. CSWRI. Avikanagar pp. 1–145.
- Swarnkar C P, Singh D, Kumar Sushil, Mishra A K and Arora A L. 2009. Study on Malpura sheep selected for resistance to *Haemonchus contortus*. *Indian Journal of Animal Sciences* 79: 577–81.
- Swarnkar C P, Singh D and Kumar S. 2012. Prevalence of benzimidazole resistant α -tubulin alleles in *Haemonchus contortus* larvae from sheep of Rajasthan. *Indian Journal of Animal Sciences* 82: 1477–81.
- Swarnkar C P and Singh D. 2012a. Epidemiology of gastrointestinal helminths in stationary and migratory sheep flocks in arid Rajasthan. *Journal of Veterinary Parasitology* 26: 112–17.
- Swarnkar C P and Singh D. 2012b. Seasonal variation in efficacy of anthelmintics and prevalence of anthelmintic resistance in gastrointestinal nematodes of sheep in Rajasthan. *Indian Journal of Animal Sciences* 82: 451–56.
- Swarnkar C P and Singh D. 2012c. Evaluation of conventional and strategic worm management schemes in sheep flocks of semi-arid Rajasthan. *Indian Journal of Animal Sciences* 82: 1482–88.
- Swarnkar C P and Singh D. 2013. *Bioclimatographs and Gastrointestinal Nematodes in Livestock of India - An Atlas*. CSWRI. Avikanagar pp. 1–148.
- Swarnkar C P, Singh D, Chopra Ashish and Prince L L L. 2014. Influence of advancement of age on intensity of strongyle infection and performance in sheep selected for resistance / resilience to infection. *Indian Journal of Animal Sciences* 84: 254–61.
- Tesfahaywet Z. 2012. Helminthosis of sheep and goats in and around Haramaya, Southeastern Ethiopia. *Journal of Veterinary Medicine and Animal Health* 4: 48–55.
- Urquhart G M, Armour J, Duncan J L, Dunn A M and Jennings F W. 2000. *Veterinary Parasitology*. English Language Book Society, England.
- van Wyk J A and van Schalkwyk P C. 1990. A novel approach to the control of anthelmintic-resistant *H. contortus* in sheep. *Veterinary Parasitology* 35: 61–69.
- van Wyk J A. 2001. Refugia – overlooked as perhaps the most potent factor concerning the development of anthelmintic resistance. *Onderstepoort Journal of Veterinary Research* 68: 55–67.
- Van Wyk J A and Bath G F. 2002. Practical methods of identifying individual animals for anthelmintic treatment within a group. *Veterinary Research* 33: 509–29.
- Van Wyk J A, Coles G C and Krecek R C T. 2002. Can we slow the development of anthelmintic resistance? An electronic debate. *Trends in Parasitology* 18: 336–37.
- Van Wyk J A, Hoste H, Kaplan R M and Besier R B. 2006. Targeted selective treatment for worm management—how do we sell rational programs to farmers? *Veterinary Parasitology* 139: 336–46.
- van Dijk J, de Louw M D E, Kalis L P A and Morgan E R. 2009. Ultraviolet light increases mortality of nematode larvae and can explain patterns of larval availability at pasture. *International Journal of Parasitology* 39: 1151–56.