



Review Article

Impact and Management of Acaricide Resistance: Pertaining To Sustainable Control of Ticks

Subhradal Nath*, Sanju Mandal, Susanta Pal, Suresh Jadhao, Namrata Ottalwar and Prabir Kumar Sanyal

Department of Veterinary Parasitology, College of Veterinary Science & Animal Husbandry, Anjora, Durg, Chhattisgarh Kamdhenu Vishwavidyalaya, Durg, Chhattisgarh, INDIA

*Corresponding author: subhradal@gmail.com

Rec. Date:	Apr 02, 2018 12:16
Accept Date:	May 27, 2018 12:52
DOI	10.5455/ijlr.20180402121612

Abstract

The economically most important ixodid ticks of livestock in tropical regions belong to the genera of Hyalomma, Boophilus, Rhipicephalus and Amblyomma. The main weapon for the control of ticks is the use of chemical acaricides. Acaricide usage is not sustainable in the long run because of the ticks becomes resistant and presence of residues in the milk and meat. Resistance is generally first recognized as failure of a drug to control parasitism. Resistance can be classified as two types: natural and genetic resistance. Natural resistance is present in all individuals and does not develop as a result of acaricidal pressure. Genetic resistance of ticks spreads by the reproduction of resistant individuals that have survived acaricidal lethal concentrations. In resistance, the user often tries to overcome the unsatisfactory performance by increasing the dose of the acaricide or the frequency of applications leading residue in food and agricultural commodities and also environmental contamination. Resistance has stimulated a great deal of research both on the problems of control and the evolutionary model that resistance provides. The development of new acaricides is a long and expensive process, which reinforces the need for alternative approaches. Focus has been directed towards the development of other options like managerial strategies, immunization, phytoacaricides, use of endosymbionts, biological control methods and exploitation of host resistance. There is urgent need of the method which is cost effective, environment friendly and minimal adverse effect on health of livestock and human being. There comes the concept of Integrated Tick Management. It involves the use of available environmental information of controlling pest and other means to avert damage caused by the pest by the most economical means with the least possible risk to people, property and the environment.

Key words: Acaricide, Ixodid Tick, Resistance, Integrated Tick Management

How to cite: Nath, S., Mandal, S., Pal, S., Jadhao, S., Ottalwar, N., & Sanyal, P. (2018). Impact and Management of Acaricide Resistance- Pertaining to Sustainable Control of Ticks. International Journal of Livestock Research, 8(10), 46-60. doi: 10.5455/ijlr.20180402121612



Introduction

Livestock production is an important integral component of the Indian agricultural production system and plays a vital role in the development of a country's economy as well as for the food and nutritional security. It has a significant role in uplifting the socio-economic status of the small and medium hold farmers. More than one fourth of the total output of the agricultural sector in India is contributed by the livestock alone Balaraman (2005). Ticks belong to phylum, Arthropoda and make up the largest collection of creatures in order Acarina. Ticks are divided into two groups: soft bodied ticks (Argasidae) and hard bodied species (Ixodidae). Hard ticks feed for extended periods of time on their hosts, varying from several days to weeks, depending on such factors as life stage, host type and species of tick. There are 899 tick species those parasitize the vertebrates including Argasidae (185 species), Ixodidae (713 species) and Nuttalliellidae (1 species) Barker and Murrell (2004). The economically most important ixodid ticks of livestock in tropical regions belong to the genera of *Hyalomma*, *Boophilus*, *Rhipicephalus* and *Amblyomma* Frans (2000).

In 2010-2011, 3.37% GDP was contributed by animal husbandry proving that it is the major sector in Indian economy DAHD&F (2010). Animal breeding plans introduced exotic germplasm to increase productivity of the animal but were susceptible to many endo and ecto parasitic diseases. Globally India ranks first in the livestock population, even though production of milk and meat is 20%-60% lesser in comparison to the world's average GOI (2012). Among ten major diseases of livestock four of them are of parasitic origin Pérez de León *et al.* (2012). Tick and tick borne diseases (TTBDs) rank fourth among the major infections of livestock and latter is regarded as the most important arthropod borne diseases of livestock, humans and companion animals Ghosh *et al.* (2007). Ticks are responsible for a variety of losses. They directly attach to the host sucking blood leading to anaemia. Tick-worry causing injection of toxins, blood loss, general stress, hide damage and irritation, leading to decrease in productivity in terms of milk, meat etc. Tick bite marks cause 20-30% depreciation in market value of hides and leather Biswas (2003). Ticks also lead to reduce fertility and difficulty in introducing improved cattle breeds into tick infested areas FAO (2004). De Castro (1997) estimated that the annual global costs associated with TTBDs in cattle amounted between US\$ 13.9 to US\$ 18.7 billion. In Brazil loses around USD 2 billion per year Grisi *et al.* (2002). Ticks act as major contributors for transmission of important disease causing agents to animals. Bovine tropical theileriosis caused by the protozoan parasite *Theileria annulata* is transmitted by the tick species of the genus *Hyalomma* worldwide, putting about 250 million cattle at risk to this important protozoan disease (Gharbiet *al.*, 2006). Estimated loss due to *T. annulata* and tick worry worldwide and India was US\$ 384.3 million and US\$ 57.2 million, respectively Mandal *et al.* (2013); Alim *et al.* (2012).

There are several methods being applied for controlling ticks and tick borne diseases. The main method among them is the use of acaricides (amidines, benzoyl phenyl ureas, benzene hexachloride/cyclodienes, carbamates, macrocyclic lactones, organophosphates and pyrethroids). Acaricide usage is not sustainable

in the long run because the striking ability of ticks becomes resistant and presence of residues in the milk and meat Nolan (1990). The use of acaricides has disadvantages, such as the selection of resistant tick populations and harmful effects on the animals, human beings and the environment García-García *et al.* (2000). The development of new acaricides is a long and expensive process, which reinforces the need for alternative approaches to control tick infestations Graf *et al.* (2004). Various methods are followed throughout the world to control ticks like use of acaricides, vaccines, biological control, physical methods and recent techniques like RNA interference Sudhakar *et al.* (2013). Certain herbal mixtures with 70% efficacy for tick control have also been reported by Regassa (2000). Tick resistance to acaricides is an increasing problem and real economic threat to the livestock and allied industries. The situation is more intense in area where one host tick like *Rhipicephalus Boophilus microplus* and *R (B) decoloratus* are prevalent as they are in continuous acaricidal pressure. The point has now been reached where such resistance must be expected in these ticks within 5 to 10 years of the introduction of any new type of acaricide, unless control practices are changed Wharton (1983).

Resistance has stimulated a great deal of research both on the problems of control and the evolutionary model that resistance provides. Experience has shown that absolute reliance on any one method of controlling ticks often fails to provide efficient, sustainable and long-term control. The integrated approach to TTBD control started in Australia in the 1960s, relying on the use of host resistance to ticks and the development of TBD vaccines. The principles stem from the concept of integrated pest management (IPM) which has been defined as the systematic application of two or more technologies, in an environmentally-compatible and cost-effective manner, to control arthropod pest populations which adversely affect the host species, in our case livestock Bram (1994).

What is Resistance?

Resistance is generally first recognized as failure of a drug to control parasitism but the formal definition of resistance is a shift in the target species susceptibility to a drug Corley *et al.* (2013). Despite the phylogenetic diversity of parasite species, resistance is a common fact of life in most branches of veterinary parasitology Sangster (2001). It is inherited and selected for because the survivors of drug treatments pass genes for resistance on to their offspring. Resistance genes appear to be carried on chromosomal DNA. These genes are initially rare in the population or arise as rare mutations in genes but as selection continues, the proportion of resistance genes in the population increases as does the proportion of resistant parasites.

Tick Resistance to Acaricide

Resistance to acaricides is the ability in a strain of ticks to tolerate doses of acaricides that would prove lethal to the majority of individuals in a normal population of the same species. Resistance is not an

adaptation that develops because of exposure to acaricides, but spreads because resistant genotypes already present in the population are favoured. The population carries the factors for resistance in low frequency before the acaricide was applied and resistant individuals are therefore selected by the application of the acaricide.

Resistance can be classified as Two Types

Natural Resistance or Tolerance

Natural resistance is present at the outset in all individuals of the species and does not develop as a result of acaricidal pressure. In a population of ticks these are those individuals that are more robust and are better equipped biochemically to counter the effects of acaricides. This ability is not necessarily passed on to their offspring. Some species have a natural resistance to acaricides. The reasons for this might be impermeability of the cuticle; behavioural traits - they may be repelled by the acaricide; and physiological processes make them not susceptible to the effect of the particular acaricide (Coles and Dryden, 2014).

Acquired Resistance

Acquired/Genetic resistance of ticks spreads by the reproduction of resistant individuals that have survived acaricidal concentrations insufficient to ensure the death of all the individuals. The acaricide acts as a selective screening process which concentrates resistant individuals already present in a population. The resistance is hereditary and the original heterogenous population is selected by acaricidal pressure to become a homogenous resistant population Abbas *et al.* (2014). Acquired resistance generally cause by-target site insensitivity and metabolic resistance.

Impact of Acaricide Resistance

When resistance starts to build up, the user often tries to overcome the unsatisfactory performance by increasing the dose of the acaricide or the frequency of applications. This type of irrational countermeasure, in addition to possible environmental contamination, contributes to the increase of acaricide residues in food, agricultural commodities and animal feed. In the environment, aquatic organisms are more susceptible to pesticides than terrestrial life forms Edwards (1993). The problems of resistance and residues are inextricably linked the latter belonging to the most important nontariff trade barriers when levels exceed the maximum residue level (MRL) allowed by the importing country or, more important, when the importing country has no defined MRL, which means that any detectable amount of the acaricide can lead to import restrictions Kunz and Kemp (1994).

Dip vats filled with acaricides have caused particular problems when they are no longer used and the surrounding land is required for more sensitive land use. The soil at the dip vat and in adjacent areas can still be contaminated with high concentrations of persistent acaricides (e.g. arsenic or organochlorides). The

content of the acaricide are potential source of soil pollutant they may cause the deterioration of soil quality. Most recently, there has been considerable concern regarding contamination of ground-water supplies as they may percolate through soil may reach to the source of ground water. In the environment, aquatic organisms are more susceptible to pesticides than terrestrial life forms (Edwards, 1993). Pyrethroids affect the environment, as they are active over a broad spectrum and are toxic to fish and aquatic organisms. They are also toxic to many non-target and beneficial species, thus decreasing natural control and increasing the need for chemical control following initial applications.

Violation of acaricides MRLs can occur and have occurred, particularly when meat is exported to a country which has a lower MRL than the country from which the meat originated, or more importantly, where the meat is exported to a country which has a zero MRL. This is the case when the particular acaricide is not registered in the importing country.

Strategies to Counteract Acaricidal Resistance

Resistance has stimulated a great deal of research both on the problems of control and the evolutionary model that resistance provides. The emergence and establishment of resistance to acaricides are extremely complex issues and needs many criteria to fulfill. It is accepted that a high degree of dominance of resistance alleles leads to rapid selection for resistance. Judicious use of acaricide may delay the emergence of resistance.

Rationale Use of Acaricides

Knowledge about monitoring, rotation and use of combination of acaricides may help in preserving the efficacies of existing compounds. To reduce the development of resistance, the knowledge of the tick species present and the resistance status should be kept in mind before the selection of acaricides. The frequency, mode and choice of acaricide are the other issues to be in consideration.

i) Saturation Strategy

Sutherst and Comins (1979) proposed saturation strategy for avoiding the selection of resistant heterozygotes which involve the use of high acaricide concentrations. The major problem with this strategy is that concentrations required to kill resistant heterozygotes have never been determined Riddles and Nolan (1986). Where resistance alleles are dominant, these concentrations are likely to be unrealistically high. Where resistance alleles are recessive or semi-recessive, these concentrations could be determined where resistance has already emerged, and recommendations could then be made on increased acaricide concentrations to be used where resistance to the particular acaricides has not yet emerged.

ii) Moderation Strategy

Delaying the development of acaricide resistance by reducing the number of treatments ('moderation strategy') was discussed in detail by Sutherst and Comins (1979). Unnecessary acaricide treatments should be discouraged; the number of treatments could most effectively be reduced by increasing the threshold of tick numbers per animal before treatment begins, especially in the first two generations in the 'active' season of the tick.

iii) Withholding of an Acaricide

Resistance management by withholding an acaricide group until others have failed is practiced in Kenya, where SP acaricides are withheld for future use. In the absence of any well-researched resistance management strategy, withholding is an attempt to delay SP resistance which will be followed with interest. One potential problem is the entry of SP resistant ticks from elsewhere. Another problem is the use of the same chemical as insecticide or for other pests and their application may have contributed to acaricide resistance in the past Baker (1978).

iv) Potentiation of Acaricide

Potentiation of acaricides by using chemicals like piperonylbutoxide (PBO), triphenyl phosphate (TPP) diethylmaleate (DEM) etc. These chemicals known for their synergists like activity and are utilized to help discern resistance mechanisms in cattle ticks through bioassays. The mode of action of Piperonyl Butoxide and substance like that is complex. According to the literature, Piperonyl butoxide stabilises the co-applied insecticide/acaricide inside the insect body and potentiates more toxins to reach their target molecules. This result in an increased mortality of the target organism, and likewise, the same effect may be observed by using decreased amounts of insecticide, i.e. synergism. The effects of synergists are not gene family-specific, as demonstrated by Young *et al.* (2005).

v) Rotation of Acaricides

Rotation or alternation of acaricides having different modes of action reduces the selection pressure for resistance to any one acaricide group. Alternating acaricides reduces the selection pressure from any one chemical, but this assumes that no resistance already exists and that the frequency of resistant individuals to each chemical used will decline during the application of the alternate pesticides. But, so far, only few laboratory reports are available regarding the beneficial effects of acaricides rotation in terms of delaying the development of strong resistance in a population that had initially a low level of resistance for an acaricide. Rotation of acaricides is costly and not easy to practice; there is no evidence as to what length of time between changes should be adopted, although most veterinarians suggest this should not be less than every two years (Maggi *et al.*, 2011).

vi) Combination of Acaricides

The use of mixtures of acaricides for delaying resistance in ticks shows promise in modelling studies Sutherst and Comins (1979). Success of mixtures is based on the expectation that one individual is unlikely to carry resistant alleles for two acaricides with different modes of action. This strategy has been tried in South Africa and simulation modeling indicates its promise. Likewise, Fernández-Salas *et al.* (2012) evaluated the synergistic effect of amitraz and permethrin against permethrin resistant *R. microplus* strain from Mexico. In this strategy, the chemicals in a combination product must be compatible and of equal persistence on the animal and they must be used at recommended concentrations. But there are chances that the individual may generate resistance against all the acaricide in use as multiple resistance and if this happens then the situation will be out of control.

Managemental Practices

The day to day works of the farm also have influence on incidence of ticks in the shed.

a) Management of Housing

It is assumed that feedlots, particularly in tropical and semitropical countries, have more possibilities to increase tick infestation rates by maximizing host finding ability of the larvae (Soberanes-Céspedes *et al.*, 2005) but, the risk of tick infestations in feedlot cattle might be reduced by making the environment unsuitable for the free-living stages of the tick. To the extent possible, cattle and buffalo sheds should be tick proof especially for the housing of purebred exotic and crossbred cattle, as they are more susceptible to the tick infestation than native cattle and buffaloes. There should be no cracks and crevices in the buildings (as the ticks hide and breed there). An acaricide channel should encircle the entire building. Heaps of dung cakes and stacks of bricks may also provide breeding places to the ticks in animal sheds and should therefore be removed regularly (Muhammad *et al.*, 2008). There should be proper of exposure sunlight in the shed and appropriate ventilation reducing the relative humidity which is one of the key factors for the hatching of tick's eggs. Entrance of new animal should be allowed after quarantine.

b) Nutritional Management

Protein–energy deficiency is an important cause of defective T-cell function (Lichtman, 2013) and T-cells have been shown to play critical role in facilitating acquired resistance to ticks (Wikel, 2013). Hosts maintained on a low protein diet failed to acquire resistance to ticks, lost weight and developed anemia while those on a high protein diet developed resistance, maintained weight and did not develop anemia. Poor quality feed not only resulted in the loss of resistance but also delayed its recovery. It has been seen that nutritional stress was one of the major causes for greater tick burdens in European (*Bostaurus*) cattle.

c) Pasture management

To reduce the environmental infestation by ticks, pasture management like rotational grazing, spelling and burning the grazed pasture is widely practiced in African countries and Australia (Mandal *et al.*, 2013); (Walker, 2011). Pasture alternation and/or rotation combined with applications of chemical acaricides has been proved as an effective way for the control of cattle ticks (Stachurski and Adakal, 2010). Pasture rotation combined with acaricide applications or habitat conversion was the most economically feasible. Pasture burning is another method which will destroy the stages like egg, larvae, nymph and adult. But these methods are not feasible in India due to various factors like shrinking pasture land in India, eliminated pasture system of grazing, tick species involved, local geography, pasture, soil type and lack of compliance by farmers (Dantas-Torres *et al.*, 2012).

Targetting Endosymbionts of Ticks

Like other parasites, ticks carry some microorganisms in their bodies. They are commonly found in arthropods usually in midgut, haemolymph and ovaries of the different arthropod vectors (Akman *et al.*, 2002). These microorganisms and ticks are essential for the survival of each other (endosymbiosis). Arthropod vectors benefit from the symbiosis and symbiosis augments the functional capabilities to facilitate their expansion to novel niches. Ticks can harbor a wide range of endosymbiotic bacteria including Rickettsia, Francisella, Coxiella, and Arsenophonus, amongst others (Alberdi *et al.*, 2012). Since endosymbionts are essential for the survival of ticks, elimination of the microorganisms would be deleterious for the survival, growth and development of ticks. Endosymbionts of ticks are almost unexplored thus far. They appear to be potential future targets for tick control (Ghosh *et al.*, 2007).

Immunization

Crude Vaccines

The use of ticks to produce resistance is effective but crude and the use of tick extract is preferred instead to induce the same response. Whilst, the extract of whole tick or its parts have proved to be very effective, the level of resistance produced has never reached the levels obtained by feeding ticks. Crude vaccines made from extracts (containing particulate or particulate plus soluble components) of semi-engorged adult female *B. microplus* gives effective immunity (Johnston *et al.*, 1986). Antibodies destroy cells lining of the tick's gut and allow blood to escape into the hemocele. Resultantly, some ticks die and the fertility of those remaining is reduced by up to 70%. The fertility of males is also reduced.

Genetically Engineered and Subunit Vaccines

Vaccination can reduce vector capacity to transmit pathogens, viz. prevention of transmission of *B. bigemina* and reduced transmission of *B. bovis* using the Bm86-based vaccine against *B. annulatus* (Pipano

et al., 2003), reduced mortality due to tick-borne encephalitis virus transmitted by *Ixodes ricinus* using a recombinant antigen derived from *R. appendiculatus* (Labuda *et al.*, 2006). In the case of ixodid tick (hard tick), anti-tick immunity is induced with microgram quantities of ixodid gut antigen preparation (Wikel, 1988). According to Fuente *et al.* (2000), 5 protective antigens have been isolated from *B. microplus*. The Bm 86 gut antigen is present throughout all tick stages. A recombinant vaccine based on a membrane bounded glycoprotein Bm86 (derived from gut of *Boophilus microplus*) has been shown to be as effective as the native antigen. Commercially available vaccines against cattle fever ticks that are approved for use outside of the United States, including Gavac® (Heber Biotec; Havana, Cuba), TickGARD (Hoechst Animal Health; Australia), and TickGARDPLUS (Intervet Australia; Australia), are based on the recombinant form of the concealed antigen, Bm86, obtained from the mid gut of *R. microplus* (Freeman *et al.*, 2010). Vaccine efficacy varies from area to area because of strain variation; therefore, a tick vaccine produced from the Australian strains might not be effective against Brazilian strains. A possible reason for such type of variation in vaccine efficacy is aminoacid sequence divergence between the recombinant Bm86 vaccine component and native Bm86 expressed in ticks from different geographical regions of the world (Freeman *et al.*, 2010). Therefore, the preliminary screening of vaccine efficacy is prerequisite before launching it in a new geographical area. Recent advances in vector biotechnology area open new opportunities for identification and vaccine development. Making tick infestation treatment cost effective and reducing the chemical residual effect on animals and environment sustainable, strategic integrated methods (Manjunathachar *et al.*, 2014).

Exploiting Genetic Resistance of Host

It has long been documented that some cattle breeds carry fewer ticks than others under the same environmental management Solomon and Kaaya (1996); Uilenberg (1999). Improved tick control following the use of tick-resistant cattle has been demonstrated in various breeds of cattle but this is manifested more strongly in zebu cattle and their crosses (Rodriguez-Valle *et al.*, 2013). In general, resistant cattle require one or two treatments per season compared with three or four in susceptible breeds. Resistance for ticks has been shown to be heritable and can be increased by breeding from cows and bulls selected for resistance David (2005). The development of cattle lines or breeds with enhanced genetically based resistance is especially attractive prospect. Zebu (*Bos indicus*; e.g., Sahiwal) and Sanga (a *Bostaurus* × *Bos indicus*) cattle, the indigenous breeds of Asia and Africa, usually become very resistant to *ixodid* ticks after initial exposure. In contrast, European (*Bostaurus*) breeds usually remain fairly susceptible. The tick resistance of Zebu breeds and their crosses is being increasingly exploited as a means of tick control. The introduction of Zebu cattle (notably Sahiwal cattle) to Australia has revolutionized the control of *Boophilus microplus* on that continent. Use of resistant cattle as a means of tick control is also becoming important in Africa and

America. Bonsma (1983) has mentioned the following factors as the basis of tick resistance/tick repellency of Zebu cattle:

- a) Thick movable hides covered with short straight, non-medulated hair (In European breeds the skin is thin and covered with wooly hair).
- b) High skin vascularity.
- c) Well-developed panniculus muscle.
- d) Sensitive pilomotor nervous system which moves their hides upon the slightest provocation.
- e) High density of sweat glands.
- f) An efficient erector pili muscle which makes the hair stand up on provocation by flies, ticks, etc. and stimulates the secretion of sebum in the hair which is repellent for ticks.

Biological Control

Ticks have numerous natural enemies, but very few species have been appraised as tick biocontrol agents (BCAs). Since the beginning of 20th centuries investigators have documented numerous potential tick biocontrol agents, including pathogens, parasitoids and predators of tick Samish *et al* (2004). Over 700 species of entomopathogenic fungi have been reported, but only 10 species are currently being developed. The most promising entomopathogenic fungi appear to be *Metarhiziumanisopliae* and *Beauveria bassiana* belongs to the family Deuteromycetes (mitosporic fungi) strains of which are already commercially available for the control of some crop pests. These have ability to penetrate the cuticle of arthropod and there by killing the arthropod. However they have some disadvantages as they are slow in killing, need high humidity to germinate and sporulate, they are susceptible to UV irradiation and some strain can potentially affect non-target arthropods. Entomopathogenic nematodes and parasitoid wasps of the genus *Ixodiphagus* have only a limited pragmatic role in tick control. Predators, including birds, rodents, shrews, ants and spiders play some role in tick control.

Ox peckers (*Buphagus spp.*) eat ticks from the bodies of infested animals. Raising poultry chicks in the cattle barns greatly reduces tick burden on the infested cattle as the chicks (particularly young ones) pick ticks from the bodies of cattle as well as ticks moving in barns. In the New World (North, Central and South America), big head ants (*Pheidolemegacephala*) are noteworthy tick predators (Muhammad *et al.*, 2008). Engorged ticks may also become parasitized by the larvae of some wasps (*Hymenoptera*) but their role in tick control is not significant. Nematodes of the families *Steinernematidae* and *Heterorhabditidae* are endowed with insect killing abilities. The third-stage juvenile (infective or dauer) stage of these nematodes are able to actively locate, parasitize and kill a wide range of insect species. These nematodes owe their insecticidal activity to bacterial symbionts (*Xenorhabdus spp.* for *Steinernematids* and *Photorhabdus spp.* for *Heterorhabditids*) which they carry in their intestine and release these bacteria into the hemocele. Bacteria proliferate and kill the insect within 24-72 hours. Owing to success in mass rearing of entomopathogenic nematodes, they are now used commercially against insect pests in agriculture and gardens in Australia, China, Japan, USA and Western Europe (Samish *et al.*, 2000). Fully engorged *B.*

annulatusticks are highly susceptible to infection by the entomopathogenic *Steinernematids* and *Heterorhabditids* with a LD50 and LD90 of upto 15 and 165 nematodes/tick/dish, respectively (Samish and Glazer, 1991). However, the results of practical application of nematodes in tick control are variable (Samish *et al.*, 2000).

Phytoacaricides

To address the problems associated with the application of chemical acaricides, focus has been directed towards the development of herbal acaricides (phytoacaricides) which are safe for animal use and there will be less chance of development of resistance to herbal formulations. Acaricidal property of plant extracts can provide a potential substitute to synthetic acaricides currently used for tick control as has been reported through testing of some plant extracts against *R. (B.) microplus*. The rhizome extract of *Acoruscalamus* was characterized and evaluated for its acaricidal effect. It proved highly efficacious and 100% final mortality within 14 days post-treatment was recorded. Certain *Stylosanthes* spp. (tropical legumes) can kill or immobilize larval ticks and the use of these plants may simultaneously improve pasture quality (Fernandez-Ruvalcaba *et al.*, 1999). *Brachiariabrizanthahas* also been shown to be lethal to *Boophilus* larvae. The leaves of tobacco (*N. tabacum*) were found to be effective against *R. haemaphysaloides* (Choudhry *et al.*, 2004) while the ethanolic extracts of *Annonasquamosa* seed and *Azadirachtaindica* leaves, bark and seed were found to have high efficacy of 70.8% and 80%, respectively, against *R.(B.) microplus* (Magadum *et al.*, 2009). Despite many advantages, the phytoacaricide market has a number of major challenges and although there has been growth, it has not grown in a comparable way to botanical medicine market in the recent years.

Integrated Pest Management (IPM) for Sustainable Tick Control

IPM is coordinated use of pest and environmental information and available pest control methods to prevent unacceptable levels of pest damage by the most economical means with the least possible risk to people, property, and the environment. Integrated control is a systematic application of two or more technologies in an environmentally compatible and cost-effective manner to control pest population. Experience has shown that absolute reliance on any particular method often fails to provide efficient, sustainable and long-term control. Acaricide usage is not sustainable in the long run because the striking ability of ticks becomes resistant. Moreover, acaricide residues in animal food products, undesirable effects on animal health and ecosystem, and the cost involved are other draw backs of the use of acaricides. So, all these factors warrant the alternate tick control strategies (Sudhakar *et al.*, 2013). There is urgent need of the method which is cost effective, environment friendly and minimal adverse effect on health of livestock and human being. There comes the concept of IPM (Integrated Pest Management) and in this case Integrated Tick management (ITM).

Here in this case the subject is tick. Initially in Australia, tick vaccine i.e. TickGARD coupled with short term acaricide usage in the name of IPM package was started. It gave an acceptable level of parasitic control Willadsen and Kemp (1999). Further similar experiments were carried out in Cuba and Mexico. It not only reduced the chemical usage but also reduced the risk of chemical resistance. In controlling animal parasitism, IPM would work by improving host resistance using non-chemical means to control parasites, using chemicals judiciously, improving monitoring of infection and resistance and understanding the host–parasite relationship. The tenet of IPM is that because several components are combined, each on its own does not have to be fully effective. At the same time, non-chemical control will remove selection pressure for resistance and help ensure that the parasites retain some susceptibility to chemicals for when their use is needed. IPM is generally more costly than chemical control and requires more careful planning as well as input from experts in several disciplines (Sangster, 2001).

Conclusion

Ticks and tick borne diseases are economically important affecting 80 % of world's cattle population and are widely distributed throughout the continents, particularly in the tropics and subtropics. These represent a substantial proportion of all animal diseases affecting the livelihood of poor farmers. The acaricidal treatment of livestock remains the most conveniently effective way to reduce production losses from tick parasitosis and tick-borne pathogens, despite repeated predictions over many decades that this is an unsustainable method. It is supported by the fact that, the global market of acaricide was to be worth around \$213.5 million in 2014 and projected to reach \$ 275.1 million in 2019. The drawback of using acaricides inconsistently and indiscriminately is the selection of acaricide resistant ticks which makes existing acaricides ineffective and thereby limiting the efficacy of existing tick control methods. Another potential problem associated with use of acaricides is the environmental contamination and the contamination of milk and meat products with chemical residues.

Absolute reliance on any of the specific method would not deliver the expected result. Therefore effective control of TTBDs is best achieved through a combination of practices like tick control, prevention of disease through vaccination, and treatment of clinical cases. Tick control methods can be grouped into chemical (using acaricides) and non-chemical methods such as, grooming, pasture spelling (i.e., leaving pastures unstocked to break the tick's life-cycle), endosymbiotic approach, biological control, genetic manipulation, use of biopesticides, herbal acaricides and vaccination with tick antigens. The type of strategy to be implemented in the different regions of the world will depend on a number of important factors. A sound knowledge of vector ecology and disease epidemiology are of great importance but the nature of the farming system, the general economic situation of the country and socio-economic considerations will also have an important influence in the success of the approach.

References

1. Abbas, R. Z., Zaman, M. A., Colwell, D. D., Gilleard, J. & Iqbal, Z. (2014). Acaricide resistance in cattle ticks & approaches to its management: the state of play. *Veterinary Parasitology*, 203(1), 6-20.
2. Akman, L., Yamashita, A., Watanabe, H., Oshima, K., Shiba, T., Hattori, M., & Aksoy, S. (2002). Genome sequence of the endocellular obligate symbiont of tsetse flies, *Wigglesworthia glossinidia*. *Nature Genetics*, 32(3), 402-407.
3. Alberdi, M. P., Dalby, M. J., Rodriguez-&res, J., Fazakerley, J. K., Kohl, A. & Bell-Sakyi, L. (2012). Detection & identification of putative bacterial endosymbionts & endogenous viruses in tick cell lines. *Ticks & tick-borne diseases*, 3(3), 137-146.
4. Alim, M. A., Das, S., Roy, K., Masuduzzaman, M., Sikder, S., Hassan, M. M. & Hossain, M. A. (2012). Prevalence of hemoprotozoan diseases in cattle population of Chittagong division, Bangladesh. *Pakistan Veterinary Journal*, 32(2), 221-224.
5. Baker, J. A. F. (1978). Resistance to ixodicides by ticks in Africa south of the Equator with some thoughts on tick control in this area. In *Tick Borne Diseases & their Vectors; Proceedings of an International Conference*.
6. Balaraman, N. (2005). Need for an organized production. *Hindu Survey Indian Agriculture*, 140-142.
7. Barker, S. C., & Murrell, A. (2004). Systematics & evolution of ticks with a list of valid genus & species names. *Parasitology*, 129(S1), S15-S36.
8. Biswas, S. (2003). Role of veterinarians in the care & management during harvest of skin in livestock species. In *Proceeding National Seminar Leather Industry in Today's perspective*. 14th & 15th November, Kolkata, India.
9. Bonsma, J. (1983). *Livestock Production, A global approach*. CBS Publishers & Distributors, Delhi, India, pp: 45-46.
10. Bram, R. A. (1994). Integrated control of ectoparasites. *Revue scientifique et technique (International Office of Epizootics)*, 13(4), 1357-1365.
11. Choudhary, R. K., Vasanthi, C., Latha, B. R., & John, L. (2004). In vitro effect of Nicotiana tabacum aqueous extract on Rhipicephalus. *Indian Journal of Animal Sciences (India)* 74, 730-731.
12. Coles, T. B. & Dryden, M. W. (2014). Insecticide/acaricide resistance in fleas & ticks infesting dogs & cats. *Parasites & vectors*, 7(1), 8.
13. Corley, S. W., Jonsson, N. N., Piper, E. K., Cutullé, C., Stear, M. J., & Seddon, J. M. (2013). Mutation in the Rm β AOR gene is associated with amitraz resistance in the cattle tick Rhipicephalus microplus. *Proceedings of the National Academy of Sciences*, 110(42), 16772-16777.
14. Dantas-Torres, F., Chomel, B. B., & Otranto, D. (2012). Ticks & tick-borne diseases: a One Health perspective. *Trends in Parasitology*, 28(10), 437-446.
15. David, S. (2005). *Ticks*. In, *The Merck Veterinary Manual*. 9th Ed., Merck & Co., Inc., Whitehouse Station, New Jersey, USA, pp: 749-764.
16. De Castro, J. J. (1997). Sustainable tick & tick borne disease control in livestock improvement in developing countries. *Veterinary parasitology*, 71(2-3): 77-97.
17. DAHD&F (Department of Animal Husbandry, Dairying & Fisheries. Basic Animal Husbandry Statistics). New Delhi: Ministry of Agriculture, Government of India; (2010). [Online] Available from: <http://dahd.nic.in/dahd/statistics/animal-husbandry-statistics.aspx>
18. Edwards, C. A. (1993). The impact of pesticides on the environment. *The pesticide question*, 13-46.
19. F.A.O. (2004). Mechanisms of acaricide resistance Resistance Management & Integrated Parasite control in Ruminants- guidelines, *Module I-Ticks, Acaricide Resistance, Diagnosis, Management & Prevention*. Rome, Pp: 25-77.
20. Fernandez-Ruvalcaba, M., Cruz-Vazquez, C., Solano-Vergara, J., & Garcia-Vazquez, Z. (1999). Short Communication Anti-tick effects of *Stylosanthes humilis* & *Stylosanthes hamata* on plots experimentally infested with *Boophilus microplus* larvae in Morelos, Mexico. *Experimental & Applied Acarology*, 23(2), 171-175.

21. Fernández-Salas, A., Rodríguez-Vivas, R. I., & Alonso-Díaz, M. Á. (2012). Resistance of *Rhipicephalus microplus* to amitraz & cypermethrin in tropical cattle farms in Veracruz, Mexico. *Journal of Parasitology*, 98(5), 1010-1014.
22. Frans, J. (2000). Final Report, Integrated Control of Ticks & Tick-Born Diseases (ICTTD).
23. Freeman, J. M., Davey, R. B., Kappmeyer, L. S., Kammlah, D. M., & Olafson, P. U. (2010). Bm86 midgut protein sequence variation in South Texas cattle fever ticks. *Parasites & Vectors*, 3(1), 101.
24. Fuente, J. D., Rodríguez, M., & GARCÍA-GARÍ, J. C. (2000). Immunological control of ticks through vaccination with *Boophilus microplus* gut antigens. *Annals of the New York Academy of Sciences*, 916(1), 617-621.
25. G.O.I. (Government of India) 2012. Report of the Working Group on Animal Husbandry & Dairying for the 12th five year plan 2012-2017. New Delhi: Planning Commission, committee/wrkgrp12/agri/AHD_REPORT_Final_rev.pdf
26. García-García, J. C., Montero, C., Redondo, M., Vargas, M., Canales, M., Boue, O., & Valdés, M. (2000). Control of ticks resistant to immunization with Bm86 in cattle vaccinated with the recombinant antigen Bm95 isolated from the cattle tick, *Boophilus microplus*. *Vaccine*, 18(21), 2275-2287.
27. Gharbi, M., Sassi, L., Dorchies, P., & Darghouth, M. A. (2006). Infection of calves with *Theileria annulata* in Tunisia: Economic analysis & evaluation of the potential benefit of vaccination. *Veterinary Parasitology*, 137(3), 231-241.
28. Ghosh, S., Azhahianambi, P., & Yadav, M. P. 2007. Upcoming & future strategies of tick control: a review. *Journal of vector borne diseases*, 44(2), 79.
29. Graf, J. F., Gogolewski, R., Leach-Bing, N., Sabatini, G. A., Molento, M. B., Bordin, E. L., & Arantes, G. J. (2004). Tick control: an industry point of view. *Parasitology*, 129(S1), S427-S442.
30. Grisi, L., Massard, C. L., Moya Borja, G. E., & Pereira, J. B. (2002). Impacto econômico das principais ectoparasitoses em bovinos no Brasil. *A hora veterinária*, 21(125): 8-10.
31. Johnston, L. A. Y., D. H. Kemp & R. D. Pearson (1986). Immunization of cattle against *Boophilus microplus* using extracts derived from adult female ticks: effects of induced immunity on tick populations. *International Journal of Parasitology*. 16: 27-35.
32. Kunz, S. E., & Kemp, D. H. (1994). Insecticides and acaricides: resistance & environmental impact. *Revue scientifique et technique (International Office of Epizootics)*, 13(4), 1249-1286.
33. Labuda, M., Trimmell, A. R., Ličková, M., Kazimírová, M., Davies, G. M., Lissina, O. & Nuttall, P. A. (2006). An antivektor vaccine protects against a lethal vector-borne pathogen. *PLOS pathogens*, 2(4), e27.
34. Lichtman, A. H. (2013). Adaptive immunity & atherosclerosis: mouse tales in the AJP. *The American journal of pathology*, 182(1), 5-9.
35. Magadum, S., Mondal, D. B., & Ghosh, S. (2009). Comparative efficacy of *Annona squamosa* & *Azadirachta indica* extracts against *Boophilus microplus*. Izatnagar isolate. *Parasitology research*, 105(4), 1085-1091.
36. Maggi, M. D., Ruffinengo, S. R., Mendoza, Y., Ojeda, P., Ramallo, G., Floris, I., & Eguaras, M. J. (2011). Susceptibility of *Varroa destructor* (Acari: Varroidae) to synthetic acaricides in Uruguay: *Varroa* mites' potential to develop acaricide resistance. *Parasitology research*, 108(4), 815-821.
37. Mandal DB, Sarma K & Saravanan M. (2013). Upcoming of the integrated tick control program of ruminants with special emphasis on livestock farming system in India. *Ticks & Tick Borne Diseases*. 4,1-10.
38. Manjunathachar, H. V., Saravanan, B. C., Kesavan, M., Karthik, K., Rathod, P., Gopi, M. & Balaraju, B. L. (2014). Economic importance of ticks & their effective control strategies. *Asian Pacific Journal of Tropical Disease*, 4, S770-S779.
39. Muhammad, G., Naureen, A., Firyal, S. & Saquib, M. (2008). Tick control strategies in dairy production medicine. *Pakistan Veterinary Journal*, 28 (1), 43-50.
40. Nolan, J. (1990). Acaricide resistance in single & multi-host ticks & strategies for control. *Parasitology*, 32(1), 145-153



41. Pérez de León AA, Teel PD, Auclair AN, Messenger MT, Guerrero FD, Schuster G. & Miller, R.J. (2012). Integrated strategy for sustainable cattle fever tick eradication in USA is required to mitigate the impact of global change. *Frontier in Physiology* 3, 195.
42. Pipano, E., Alekseev, E., Galker, F., Fish, L., Samish, M., & Shkap, V. (2003). Immunity against *Boophilus annulatus* induced by the Bm86 (Tick-GARD) vaccine. *Experimental & applied acarology*, 29(1), 141-149.
43. Riddles, P.W. & Nolan, J. (1986). Prospects for the management of arthropod resistance to pesticides. In Proceeding 6th International Congress of Parasitology (M.J. Howell, ed.). Australian Academy of Science, Canberra, 679-687.
44. Rodriguez-Valle, M., Moolhuijzen, P., Piper, E.K., Weiss, O., Vance, M., Bellgard, M. & Lew-Tabor, A. (2013). *Rhipicephalus microplus lipocalins* (LRMs): genomic identification & analysis of the bovine immune response using in silico predicted B & T cell epitopes. *International Journal of Parasitology*. 43, 739-752.
45. Samish, M., & Glazer, I. (1991). Killing ticks with parasitic nematodes of insects. *Journal of invertebrate pathology*, 58(2), 281-282.
46. Samish, M., Alekseev, E., & Glazer, I. (2000). Biocontrol of ticks by entomopathogenic nematodes: research update. *Annals of the New York Academy of Sciences*, 916(1): 589-594.
47. Samish, M., H. Ginsberg & I. Glazer (2004). Biological control of ticks. *Parasitology*, 129(S), 389-403.
48. Sangster, N.C. (2001). Managing parasiticide resistance. *Veterinary Parasitology* 98, 89-109
49. Soberanes-Céspedes, N., Rosario-Cruz, R., Santamaría, V. M., & García-Vazquez, Z. (2005). General esterase activity variation in the cattle tick *Boophilus microplus* & its relationship with organophosphate resistance. *Tec Pecu Mex*, 43(2), 239-246.
50. Solomon, G., & Kaaya, G. P. (1996). Comparison of resistance in three breeds of cattle against African ixodid ticks. *Experimental & Applied Acarology*, 20(4), 223-230.
51. Stachurski, F., & Adakal, H. (2010). Exploiting the heterogeneous drop-off rhythm of *Amblyomma variegatum* nymphs to reduce pasture infestation by adult ticks. *Parasitology*, 137(7), 1129-1137.
52. Sudhakar, N. R., Manjunathachar, H. V., Karthik, K., Sahu, S., Gopi, M., Shanthaveer, S. B., Madhu, D. N., Maurya, P. S., Nagaraja, K.H., Shide, S. & Tamilmahan, P. (2013). RNA interference in parasites: prospects & pitfalls. *Advances in Animal & Veterinary Sciences*, 1(2S), 1-6.
53. Sutherst, R. W., & Comins, H. N. (1979). The management of acaricide resistance in the cattle tick, *Boophilus microplus* (Canestrini) (Acari: Ixodidae), in Australia. *Bulletin of Entomological Research*, 69(03), 519-537.
54. Uilenberg, G. (1999). Immunization against diseases caused by *Theileria parva*: a review. *Tropical Medicine & International Health*, 4(9).
55. Walker, A. R. (2011). Eradication & control of livestock ticks: biological, economic & social perspectives. *Parasitology*, 138(08), 945-959.
56. Wharton RH. (1983). Tick-borne livestock diseases & their vectors. Acaricide resistance and alternative methods of tick control. *World Animal Review, (FAO)*, 36:34-41.
57. Wikel, S. (2013). Ticks & tick-borne pathogens at the cutaneous interface: host defenses, tick countermeasures, & a suitable environment for pathogen establishment. *Frontiers in Microbiology*, 4, 337.
58. Wikel, S. K. (1988). Immunological control of hematophagous arthropod vectors: utilization of novel antigens. *Veterinary Parasitology*. 29(2-3), 235-264.
59. Willadsen, P. & Kemp, D. H. (1999). Past, present & future of vaccination against ticks. Proceedings of the IV Seminario Internacional de Parasitologia Animal, Puerto Vallarta, Mexico, 131-140.
60. Young, S. J., Gunning, R. V., & Moores, G. D. (2005). The effect of piperonyl butoxide on pyrethroid resistance associated esterases in *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae). *Pest management science*, 61(4), 397-4.

