Tick, fly, and mosquito control – Lessons from the past, solutions for the future

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Tick, fly, and mosquito control—Lessons from the past, solutions for the future☆

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Abstract

In order to continue to produce livestock in a sustainable fashion, it is suggested that what was used in the past will continue to form the mainstay of future control. For the foreseeable future, we must conserve what we have, and use it in combination with all the principles of integrated pest management, namely strategic and focussed treatments of animals, environmental control of breeding sites, disease management (including the principles of enzootic stability), and resistant breeds. Whilst new technologies, such as the development of vaccines both against the insect pest in some cases or the disease they transmit in others, and genetic engineering hold out some hope for the future; these are not sufficiently well advanced to permit wholesale application.

Article Outline

1. Introduction

Control of ticks, flies, and mosquitoes in the recent past has relied heavily on the use of effective chemicals, such as the arsenicals, chlorinated hydrocarbons, organophosphates, carbamates, formamidines, pyrethroids, macrocyclic lactones, and more recently the Insect Growth Regulators (IGRs). Success in the chemicals' use has depended on the organism's susceptibility to them, management of their application, and availability.

As we move forward into the new century, there are a number of factors that will influence future control strategies.

• Prospects for development of new drugs in the 21st century will be determined by economic, social, and scientific factors. There has been significant consolidation in the chemical/veterinary pharmaceutical industry, and there is huge pressure to maximise profit. Resources are limited, with the focus having shifted to those areas where consistently higher returns on investment can be expected (Geary and Thompson, 2003).

• In terms of control, two distinct needs exist: In the developed countries, there is an emphasis on maximal production coupled with a need to reduce reliance on chemotherapeutics (residue reduction, antimicrobial resistance). In the developing nations, the presence of ticks and the diseases that they transmit have been huge constraints to the intensification of livestock production. It is estimated that livestock form a component of 70% of the livelihood of the world's poor (Perry et al., 2000). Reasons why animal diseases are an every day occurrence include lack of knowledge, lack of access to acaricides, lack of drugs, and a lack of resources.

• In Western consumer societies, per capita consumption of meat is expected to decline because of negative views about the consumption of animal protein, environmental impacts, and animal welfare. In the developing world, malnutrition is rife. Protein sources in the form of meat and milk provide a means of overcoming this. Annual demand for meat is predicted to grow by 2.8%, and that for milk by 3.3%. Growth rates of 0.6% for meat and 0.2% for milk are predicted for the developing world. In addition to the above, livestock is an important source of purchasing power, and they provide a valuable asset in providing fertiliser for crop production (Perry et al., 2000).

• It is also clear that traditional management of production systems is changing, and in certain developed countries green or organic agriculture is becoming more appealing. This suggests that parasitism is increasing in these areas. In the resource-poor or developing countries, parasitism is an issue because of lack of accessibility to products and knowledge, and lack of money. Globally, the four general disease categories with the highest rank impact on the poor include gastro-intestinal parasites and ectoparasites (Perry et al., 2000).

• Resistance to the currently available insecticides has been recorded for ticks, flies, and mosquitoes—in some areas, resistance to all classes of insecticides used for control in one species has been recorded.

Based on the abovementioned facts, what solutions do we have for future control?

1.1. Ticks

Ticks are haematophagous arthropods belonging to the class arachnids. Once they attach to a host for a blood meal, they can cause irritation and infection of the skin, anaemia, and transmit disease.

In South Africa, inadequate data exist on direct economic losses that can be attributed to ticks, and the diseases that they transmit. Losses were projected at about 70–200 million South African rands per annum in Bigalke, 1980, whilst some 36,000 small-stock units are lost to Karoo paralysis (caused by *Ixodes rubicundus*) (Spickett and Heyne, 1988). In Australia, losses caused by the blue tick *Rhipicephalus* (*Boophilus*) *microplus* are estimated to be 100 million Australian dollars per annum. Live-mass gains and milk yield has also been known to drop. Norval et al., 1988a and Norval et al., 1988b estimated that for each fully engorged brown ear tick (*Rhipicephalus appendiculatus*), a loss of 4.4 g (±0.08) in live-mass gain is recorded. *Rhipicephalus* (*Boophilus*) spp. in Australia resulted in losses of about 0.6–1.5 g, and *Amblyomma hebraeum* in Zimbabwe about 10 g per tick.

It is clear that ticks, and the diseases that they transmit, have been a major constraint to the improvement of livestock industries, particularly in the developing countries for the past 100 years.

Tick eradication has been the method of choice for control, and has been successful in the case of *Rhipicephalus* (*Boophilus*) spp. in the United States and some areas of Argentina, as well as for the tropical bont tick (*Amblyomma variegatum*) in the Caribbean. Success has always been determined by the isolation of the affected area, and the ease with which reinfestation of the specific tick species can be prevented.

East Coast Fever (ECF) was successfully eliminated from large areas of Southern Africa – not through tick removal, since alternative tick hosts were present – but rather because close interval dipping (5–5–4 day) and quarantine was used. In Australia, efforts to eradicate the blue tick have proved unsuccessful.

In the main, tick control has been achieved through the use of acaricides. In many countries, the sale of acaricides accounts for a major portion of the veterinary market. In South Africa, total sales in the veterinary market for 2003 were R 872 million, of which R 175 million (22%) were ectoparasiticides. If endectocide sales are also included, the market share increases to 30%. Currently, there are 104 products registered for tick control in South Africa. These products comprise five chemical groups with 22 different actives.

Success stemming from the use of the products depends on the susceptibility of the tick to the acaracide used, as well as the availability of treatments. As a result of the war of liberation in Zimbabwe, veterinary services in the communal areas collapsed, and dipping services were interrupted with disastrous consequences. Some 1 million head of cattle died of tick-borne diseases. These deaths were most likely caused by a lack of immunity, resulting from cattle previously being too effectively dipped, and the natural disease challenge and maintenance of enzootic stability being disrupted.

Enzootic stability is an epidemiological state of the population, in which clinical disease is rare despite high levels of infection. Where enzootic stability exists, young animals exposed to certain tick-borne diseases do not become ill because of maternally derived immunity or age resistance. This exposure results in the development of a long-lasting immunity. If animals are not exposed to infection when they are young, they can develop severe disease at a later date. The immunity can also be lost if older animals are not exposed to infection. Thus, animals should be regularly exposed to the bites of infected ticks, in order to maintain immunity to the disease. If this does not happen, the immune system will not be stimulated, and outbreaks of tick-borne disease are the likely consequence. This situation is known to exist for both babesiosis and anaplasmosis in cattle. In the case of ECF, it occurs sporadically.

In addition to the use of acaricides, attempts have been made in Australia to achieve a degree of disease control through the use of a vaccine against the blue tick, and by farming with cattle breeds that are naturally resistant to tick infestations.

With few exceptions, it is not practical to consider the complete eradication of ticks. Continuous and frequent application of chemicals is not sustainable on environmental, disease, and economic grounds.

1.2. Blood-feeding flies and myiasis

Many flies and mosquitoes parasitise humans and/or livestock. Life cycles of parasites differ. In humans and livestock, life cycles can differ substantially.

Flies can cause severe irritation, often associated with production losses, reduced value of hides, and disease. Levels of and types of disease transmitted by flies are strongly influenced by environmental factors, which in turn are affected by climate and specific features of the agricultural and ecological landscape.

Blood-feeding flies – such as tabanids, horn flies, and stable flies – are flies of pastured livestock. Stable flies can also be a serious pest in stables, however. Specifically, tabanids are a major livestock pest. Their bites are painful, and severe local reactions to the bites may develop. Blood loss due to bites can be significant. Furthermore, tabanids are mechanical vectors of a range of pathogenic agents of livestock, such as *Anaplasma marginale* and *Trypanosoma vivax*.

Horn flies (*Haematobia irritans*) and the buffalo fly (*Haematobosca stimulans*) are also major pests. Adult flies spend most of their time on the backs of cattle and buffalo, taking repeated small meals. Massive numbers infest the animals, causing severe biting stress and interference with feeding, resting, and other normal activities of cattle. In Florida in the United States, it is estimated that horn flies alone cause losses of up to US$ 36 million per annum. In Australia, the losses associated with buffalo fly infestations are mainly due to reductions in feed intake, with weight losses due to a moderate infestation (200 flies a day on the cattle over a 100-day fly season) averaging 15 kg per animal. Milk production drops by more than half a litre per day.

The presence of stable flies, such as *Stomoxys calcitrans*, may also result in significant weight loss, and loss of blood in cattle. Stable flies transmit certain diseases mechanically, and can be important mechanical vectors in areas where tabanids are absent.

Blood-feeding flies that require special mention are the tsetse flies or *Glossina* spp. Tsetse flies are the vectors of trypanosome parasites that cause animal and human sleeping sickness. The flies occur on about 10 million km^2 of sub-Saharan Africa, and constitute a major impediment to agricultural and rural development in the infested areas. It is estimated that lost milk and milk production, together with the costs of the trypanosomosis-control programmes, cost between US$ 6 million and 1.2 billion per annum (Swallow, 2000).

Myiasis-producing flies are those with larvae that use body fluids or exudates of the living host as a food source for growth and development. Two main groups of myiasis-producing fly species can be distinguished, i.e. obligatory parasites and facultative parasites. The former must develop on live hosts, and the latter can develop on both living and dead organic matter (Hall and Wall, 1995). The three major families of myiasis-producing flies are the Oestridae (including the subfamilies Oestrinae, Gastrophilinae, Hypodermatinae, and Cuterebrinae), the Calliphoridae (or blowflies), and the Sarcophagidae (or fleshflies).

Flies of the family Oestridae (including the nasal/horse bot and warble flies) have larvae (maggots) that feed on the host. The larvae cause severe irritation, with consequent losses in production and damage of tissues. Warble flies irritate cattle, and result in weight loss and reduced milk yields. Larvae also irritate body tissue. There is depreciation in the carcass value, and damage to the hides where they are perforated. Older cattle may become sensitized to the larvae because of previous infections, and show anaphylactic reactions when larvae die or are broken up during extraction. Horse bot fly larvae are gastrointestinal parasites of horses that may cause severe inflammatory reactions.

The Calliphoridae and Sarcophagidae are divided according their parasitic habits. Some larvae are obligate parasites (some screwworm species), and others are facultative ectoparasites. Infestation occurs after a female has laid eggs in open wounds caused by engorged ticks, castration, dehorning, branding, wire cuts, or a multitude of other causes. The New World screwworm fly (*Cochliomyia hominivorax*) was a major pest of livestock in large parts of Central and South America, and was discovered in Libya in 1988. The Old World screwworm (*Chrysomya* spp.) is at present confined to the Old World; it is found throughout much of Africa (from south of the Sahara to northern South Africa), on the Indian subcontinent, and in Southeast Asia (from southern China through the Malay Peninsula and the Indonesian and Philippine islands to New Guinea) (Zumpt, 1965). It has been introduced into several countries on the west coast of the Persian Gulf. Screwworm infestations may result in significant economic losses. For example, before the eradication of the screwworm in USA, annual losses in the livestock sector from screwworms were estimated to be more than US$ 140 million.

There are three subfamilies of mosquitoes: Anophelinae, which are responsible for, among others, the transmission of malaria and the various viruses that cause equine encephalitis; Culicinae whose genera transmit a large number of diseases in both humans and animals; and the Toxorhychitinae which do not feed on blood.

In domestic animals, the mosquitoes/midges transmit Rift Valley fever, African horse sickness, 3-day stiff sickness, blue tongue, and heartworm in dogs and can cause allergies, such as sweet itch. They also cause severe biting stress that can result in deaths and make areas uninhabitable for livestock. Worldwide, some 42 named and 11 unnamed arboviruses are *Culicoides* associated (Coetzer et al., 1994).

Up to now, control of flies and mosquitoes has been based on either reducing the interaction between the insect and livestock, or by reducing the population density of their larval stages or adults.

Methods to reduce the host/parasite interaction between the blood-feeding fly or fly species that cause myiasis have been extensively used. For example, repellents have shown to be effective in preventing *Stomoxys* and tabanid species from attacking livestock. In the case of tsetse flies, on the other hand, currently known repellents have been far less effective. A reduced interaction can also be achieved by keeping livestock away from known fly habitat or breeding sites. For example, keeping cattle indoors protects them to a large extent from the bites of tabanids or tsetse flies. In South Africa, herding livestock in moist low-lying areas during the day, and removing them to higher ground in the late afternoons and evenings to reduce interaction with mosquitoes/midges, used to be common practice. Finally, in the case of myiasis-causing fly species, interaction and thus infestation by larvae can be treated by dressing of wounds.

Reduction of the adult or larval population density has relied mainly on the use of chemicals, although biological methods have been successfully applied. A whole range of synthetic insecticides applied as dips, sprays, pour-ons, or incorporated in ear tags, have been used over the years. More recently, use is being made of “Insect Growth Regulators” that affect insect growth and development. Similarly, avermectins (the active components of some insecticidal components) control adult and larval fly stages. The latter two groups of components with insecticidal activity have been very effective in preventing larvae of several fly species from developing in dung. Prevention of mosquito/midge bites has been achieved through the treatment of larval habitats with the organophosphates (temephos), IGRs, or more recently biological control agents like *Bacillus thuringiensis* var. *israelensis*; and the use of pyrethroids in one form or another on the animals. Destruction of habitat or breeding sites reduces adult or larval populations. Water management practices or removal of dung may have a significant impact on the density of *Stomoxys* or tabanid species, respectively. Sterile Insect Technique (SIT) has successfully controlled certain fly species. SIT involves mass breeding huge numbers of target insects, and sterilizing the males by exposing them to low doses of radiation. These sterile male flies are released in the infested areas, where they mate with wild females. If the sterile males vastly outnumber the fertile wild males, the wild fly population quickly dies out. SIT was applied in the eradication the New World screwworm from North Africa in the early 1990s, and was one of the tools used to eradicate tsetse from the island of Zanzibar (Vreysen et al., 2000).

Successful management of fly borne problems in livestock relies on the selection of an appropriate control method or a combination of methods. Such an integrated approach requires a good knowledge and understanding of the peculiarities of the biology and ecology of a particular species. These approaches have been implemented in the control of several fly species.

Especially for tsetse flies, detailed studies of their ecology and behaviour, and the exploitation of specific aspects of their ecology and behaviour, have resulted in an arsenal of control methods that have been successfully exploited. As a result, tsetse-control methods have ranged from drastic clearing of their habitat and elimination of the host, to exploiting the tsetse's visual and olfactory responses to insecticide-treated artificial baits (Vale, 1993).

Indeed, prior to the development of the organochlorines in the 1940s, bush clearing and game elimination (some 150 million head of game were slaughtered) were the major means of controlling tsetse flies. With the advent of insecticides, such as gamma BHC, DDT, and dieldrin, toxic treatment from the air (aerial spraying), or from the ground (ground spraying) of the tsetse habitat became feasible. The persistence of the molecules used meant that many generations of flies were affected. Despite their effectiveness, this type of insecticide application was indiscriminate and had important environmental impacts. In Southern Africa, for example, ground spraying resulted in the deaths of non-target organisms (Nagel, 1995).

To reduce environmental impacts, discriminative methods of ground spraying were developed. Knapsack sprayers were used to selectively spray the tsetse's preferred resting sites. Application rates were reduced in the case of DDT, from 1 to 200–250 kg ha^{-1}, and approximately 20% of the vegetation was treated. This control approach, whilst being more environmentally friendly, remained expensive and labour intensive.

Aerial spraying techniques also improved considerably (Allsopp, 1984). By the late 1970s, a sequential drift technique was developed. Reduced spray volumes and lower insecticide concentrations resulted in reduced residual activities. This Sequential Aerial Spraying Technique (SAT) had few serious side effects, and the observed drops in the population density of non-target organisms were usually only temporary. The highly persistent organochlorines were superseded by easily degradable and less persistent endosulfan or synthetic pyrethroids. Nevertheless, environmental concerns remained, and the costs of aerial spraying operations were high. Furthermore, effectiveness of aerial spraying was only ensured in areas that were sufficiently large and isolated. Reinvasion concerns prompted the development of tools for use in areas subjected to continuous invasion.

Since their development in the 1980s, artificial baits (traps and targets) have been used successfully in many tsetse-infested areas of Africa. A better understanding of the interaction between the tsetse and its environment has resulted in a gradual improvement of the bait's effectiveness, and its environmental friendliness (Vale, 1993). Furthermore, bait systems offer the additional advantage of being simple, so that bait technology can be transferred to communities living in tsetse-infested areas. More recently, insecticide-treated cattle (mobile live baits) have been used as part of an integrated control approach. This method has been extremely effective under particular epidemiological circumstances, and offers the added advantage of controlling ticks and some biting flies at the same time. In Tanzania between 1991 and 1996, trypanosomosis decreased from >19,000 to <2400 cases, and deaths from >1000 to 29 after pyrethroid-dipping was introduced into the Kagera region (Hargrove et al., 2000). On four ranches in the region, tsetse were almost eliminated, and trypanosomosis prophylaxis was no longer used. A similar treatment regimen at the Mkwaja ranch in the Tanga region, on the other hand, was less effective. This was attributed to the size of the treated area, and the invasion pressure of tsetse in the treated area (Hargrove et al., 2000). Because of the widespread distribution of tsetse and the fly's mobility, eradication of tsetse has proven to be difficult. Nevertheless, tsetse were eradicated from Zanzibar through a combination of bait technology and SIT (Vreysen et al., 2000). One of the major factors contributing to this success was the fact that there was little chance of reinvasion by the flies.

Although the control of insects and ticks relies heavily on the use of chemicals, the development of resistance to these compounds is a serious threat to the sustainability of this approach. The development of resistance in arthropods is dependant on the volume and frequency of application of the insecticides, as well as the insects' life cycles. The single-host tick, *Rhipicephalus* (*Boophilus*), has a short life cycle, and produces many young; whilst multi-host ticks have a longer life cycle. There has therefore been faster development of resistance in *Rhipicephalus* (*Boophilus*) spp. In tsetse, resistance to insecticides has not yet developed. This is because of the low reproductive rate of tsetse. On the other hand, more than 100 rapidly reproducing mosquito species are resistant to one or more insecticide, and there have been numerous reports of resistance in fast-reproducing fly species (Hemingway and Ranson, 2000). Acaracide-resistance in ticks is common particularly in *Rhipicephalus* (*Boophilus*) spp.

It is thought that insecticide-resistance is caused by two main mechanisms, namely metabolic and target site. Metabolic resistance is determined by three major enzyme systems: esterase, glutathione-S-transferase (GST), and mono-oxygenases. Elevated esterase levels confer broad-spectrum organophosphate resistance in *Culex* spp. Many insecticide-resistant insects have elevated levels of GST's, whilst elevated mono-oxygenase activity has been associated with pyrethroid resistance.

Target site resistance has been recorded for insecticides that target the nervous system (organophosphates, carbamates, organochlorines, and pyrethroids). The organophosphates and carbamates target acetylcholinesterase (AChE). A particular receptor, AChE1, appears to be specifically involved in resistance. GABA receptors (heteromultimeric gated chloride ion channels) are involved in the resistance to dieldrin, and are the site of action for pyrethroids, avermectins, and cyclodienes.

Both DDT and the pyrethroids exert their effect by causing persistent activation of the sodium channels, which delays the normal voltage-dependant mechanism of inactivation. Sodium channel insensitivity has been recorded for *Musca domestica* (Farnham and Sawicki, 1976) and mosquitoes.

The molecular biology of resistance is complex. It is thought to result from the over-expression of enzymes capable of detoxifying insecticides or amino acid substitutions within the enzymes that alter the enzymes' affinity for the insecticide. In mosquitoes, increased expression of genes encoding for the major metabolic enzymes is a common cause of resistance. Increased enzyme production may be associated with a lower fitness cost than that associated with structural gene alterations.

The exact genetic mechanisms of resistance due to increased metabolism are not always known. In the sheep blow fly (*Lucillia cuprina*), organophosphate resistance (malathion) is caused by a single amino acid substitution in the E_3 esterase (Campbell et al., 1998). Similar phenotypes have been observed in some *Anopheles* spp. A second amino acid substitution confers broad cross-resistance to many different organophosphates, but not malathion in the sheep blowfly and house flies (Newcomb et al., 1997).

Gene amplification is responsible for elevated esterase systems in *Culex* spp. (Mouches et al., 1986). Esterases can also be elevated by changes in regulatory elements, rather than gene amplification.

There are two classes of GSTs playing a role in the metabolism of insecticides. Resistance mutations result in elevated levels of the enzyme by disrupting the normal function of the transacting repressor. In the case of the mono-oxygenases, increased transcription of genes or mutations in *trans*-acting regulatory genes is thought to be responsible for increasing resistance to insecticides.

Target site resistance is most commonly caused by non-silent point mutations. For the mutation to occur, the primary function of the target site cannot be lost. Function of the site will be impaired to a degree, and this is reflected in the fitness of the individual in the absence of insecticide selection. Fitness cost is of value if the resistance is to persist in the field.

Sodium and GABA channels have been cloned in insects (resistant and susceptible), whilst AChE channels have been characterized in *Drosophila* spp. The resistance phenotype (Kdr) causes a reduction in the sensitivity of the sodium-gated channels in insects. A PCR test determines whether individuals are homozygous or heterozygous, and is used to detect early resistance in the field and manage it accordingly. AChE mutations have been isolated, but not cloned. In *Culex*, insensitive AChE is associated with a high fitness cost.

2. Future control

Flies, ticks, and mosquitoes will continue to be important pests in the future. Their effective control will not only be determined by the effectiveness of a particular method or combination of methods, but also by the sustainability of the control approach. Some important issues related to the sustainable control of ectoparasites are listed below.

2.1. Environmental sustainability

The acceptability of future control efforts for flies and ticks, will be determined by the direct and indirect effects of the control interventions on the environment. Environmental rules and regulations require that each control strategy is selected to its target species. Such selective control has had important repercussions for the approach adopted in the development of new control methods. Selectivity can be achieved by exploiting certain species, identifying specific aspects of the behaviour of the target organism, and by the development of chemical compounds that have a minimal impact on non-target species.

The direct environmental effects of currently available methods have been the subject of many environmental impact assessments, and are generally well known. Nevertheless, the application of known methods in a new environment and/or against a new target species, may have an unexpected environmental impact and require additional impact studies. It has been shown recently that insecticide-treatments of cattle to control tsetse have an important and unexpected effect on the population of dung beetles (Vale et al., 2004). Such adverse effects can be minimized, by promoting the development of highly degradable insecticides and acaricides with selective toxicity (De Deken et al., 2004).

The environmental sustainability of currently available and new control methods based on the use of chemicals, is also dependent on the proper application method. The latter becomes increasingly important, when the responsibility for ectoparasite control is transferred to livestock owners. To ensure proper use of chemicals with minimal effect on the environment, appropriate training and extension must be emphasised.

Advances in molecular biology, cell biology, and genomics have allowed us to identify weak links in the disease transmission of vectors. Using techniques, such as transgenesis or paratransgenesis, vectorial capacity can be modulated. Genetically modified/engineered insects, that are unable to transmit pathogens, can replace their susceptible counterparts in nature. Similarly, the introduction of foreign genes into vectors of medical and agricultural importance, such as the mosquito vector *Anopheles* or the tsetse fly, will modify the target population genetically (Aksoy, 2003). Although control through genetic modification has not yet proven to be effective under field conditions, some attention could be paid to its potential environmental impacts.

As with all biotechnology applications, potential risks must be weighed against the potential benefits. Potential risks that have not been addressed include environmental issues, if the modified trait in the insect/animal provides it with a fitness advantage ecosystems could be conceivably be disrupted. In the case of genetically modified insects, they are intended for permanent establishment in the environment and the new genetic trait has to be “driven” into the wild population. The potential to recall these GM insects should adverse events be recorded will be difficult if not impossible.

It is clear that the regulators will have to take care to avoid possible environmental, public health, agricultural and food-safety risks from genetically modified insects.

Finally, an effective control method will undoubtedly have its impact on livestock production. Especially in some developing countries, increased livestock productivity and livestock density is expected to have significant adverse effects on the environment. Such undesired effects can be counteracted, e.g. by altering the respective livestock management practices.

2.2. Socio-economic sustainability

Socio-economic sustainability applies particularly to developing countries. Three issues are of importance: the cost of the control method, the willingness to pay for the control method, and the availability of the control method. Willingness to pay for a particular control method is an issue of increasing importance in developing countries, and is not necessarily linked to the cost. In the past, veterinary service departments had technical and financial responsibility for the control of ectoparasites, such as ticks and tsetse flies. As a result of structural adjustment programmes in many developing countries, responsibilities for the control of ectoparasites have now, to a large extent, been transferred to the livestock owners. Not all livestock owners have accepted this change. They continue to consider control of ticks and flies (mainly tsetse flies) the responsibility of Government. Their willingness to pay for a control intervention is low. Even when livestock owners are willing to pay, the change of responsibility has important financial repercussions. Many veterinary companies have tried to reduce the financial burden of control by, for instance, packaging insecticides into small packs (50 and 100 ml containers) for use by one livestock owner, and often with instructions printed on them or supplied as a pamphlet in the local language. Whilst this addresses the reduced scale and volume at which products are used, small packs come at a premium cost. In communities that have access to a dip tank, money structures are being established to allow for the collection of money from livestock owners that use the dipping infrastructure. Despite the increased responsibility of the livestock owner in controlling certain ectoparasites, governments will have to provide support in terms of the establishment of functional delivery systems for educational programmes and chemical products or other tools required for the control, as well as functional marketing systems with fair prices.

2.3. Technical sustainability

Technical sustainability is determined largely by the effectiveness of the method or combination of methods used. In the case of insecticides and acaricides, the development of resistance against the active compounds is a reason for concern. Although the development of resistance may be difficult to avoid in some target species, its development can be slowed by proper chemical use. Resistance management is paramount if we are to conserve the existing insecticides for further use. Rotations, mosaics, and mixtures have all been proposed as means of countering resistance. With the development of different biochemical and molecular techniques for testing resistance genes and their frequency, assessments of the efficacy of proposed control techniques can be made on a regular basis.

Technical sustainability also relates to the appropriate use of a control method. Often control methods are transferred, without considering the epidemiological circumstances under which a particular method is effective. This is, for example, the case with the insecticide-treatments of cattle to control tsetse. In the Eastern Province of Zambia, the method has been highly successful. The treatment of approximately 20,000 head of cattle with cyfluthrin pour on (Cylence®, Bayer) every 7 weeks, resulted in a decline in the incidence of trypanosomosis from a mean of 12% prior to application to 0.9% (Van den Bossche et al., 2004). In eastern Zimbabwe, on the other hand, the method did not prevent reinvasion of tsetse (Warnes et al., 1999).

Unwanted side effects may also affect technical sustainability of a control method. A good example is the effect on ticks of insecticide-treatments of cattle to control tsetse. Along the North Eastern border of Zimbabwe, deltamethrin dips and pour-ons were extensively used in an attempt to counteract the invasion by tsetse from neighbouring Mozambique. A survey to determine the effects on the epidemiology of babesiosis found that the prevalence of antibodies against *Babesia bigemina* in adult cattle treated with deltamethrin was 2.1%, compared to 43.2% in adjacent areas, where were treated with short residual action acaracides (Van den Bossche and Mudenge, 1999). This suggests that the long-term and systematic use of insecticides created an enzootically unstable situation for babesiosis. Since insecticide-treatments of cattle are employed widely for the control of tsetse in an integrated and sustainable manner, ways of doing this without destroying enzootic stability need to be established (Van den Bossche et al., 2002). For both ticks and tsetse, interventions could be timed to coincide with those periods when their population density is highest or most vulnerable to control measures. An excellent understanding of the population dynamics for both groups is required. In Eastern Zambia, where trypanosomosis is enzootic and babesiosis enzootically stable, tsetse are most vulnerable during the cold/hot dry season; and tsetse control interventions have the highest impact at these times. Theoretically, by restricting treatment to animals during the cold and hot dry season, tsetse challenge may be reduced sufficiently without interfering too much with the population density of ticks and disease challenge.

Studies have shown that *Glossina morsitans morsitans* and *Glossina pallidipes* prefer feeding on adult cattle. Hence, insecticide-treatments of adult cattle may be sufficient to obtain a desirable effect on the tsetse population. The same applies for ticks. Often a small number of animals carry the largest number of ticks ("tick taxis"). By treating only these animals, it may be possible to reduce the number of tick treatments to obtain a desirable effect.

Insecticides can also be selectively applied to predilection feeding sites of the tsetse species involved. Similarly for ticks, the use of acaricide applicators, such as the Duncan Applicator, which gives the animal a good dose of acaricide around the ears, can be considered in seasons where the challenge from the brown ear tick (*R. appendiculatus*) is very high.

Considering the serious drawbacks that may impede the sustainable control of flies and ticks, the exploitation of the individual animal's immunity or tolerance is an attractive control approach. *Bos indicus* cattle are more resistant to many tick and fly borne diseases, as well as to attack by ticks, than the *B. taurus* breeds. This resistance is related to natural selection, since the *B. indicus* breeds have lived in the same area with the ticks for aeons (Spickett et al., 1989).

Acquired resistance to tick bites is based on hypersensitivity reactions (Singh and Girschick, 2003), which result in a reduction of the weight of engorged females, increased feeding times, reduction in the number of eggs laid, and reduced egg viability. Cattle do show an immune response to ticks, and those that have been infested with *R.* (*Boophilus*) *microplus* will produce antibodies to the membrane glycoproteins as well as to BM 86, a tick gut protein. BM 86 has been synthesised using recombinant DNA technology, and a vaccine has been made from this. This vaccine, whilst not killing ticks directly, has shown some promising results. Its use resulted in a successive reduction in tick numbers over a season, because of a reduction in the ticks' fertility. The efficacy varied between different tick strains, however (Willadsen, 1990). Increased levels of tick control can be achieved, if increased antibody levels are attained. Immunological responses to ticks are better, if more complex mixtures of antigens are used. Therefore, the development of a polyvalent vaccine should bring better efficacy.

Vaccines have been developed to protect against the mammalian stages of many of the tick-borne diseases, such as babesiosis, heartwater and anaplasmosis. Up until now, these vaccines have been costly, difficult to use, and have had problems with safety, efficacy, and cross-protectivity. Currently, a number of research efforts are developing characterising organism/tick cell culture systems, which will yield immunogenic material different and complemetary to mammalian culture systems and improved vaccines.

Molecular vaccines are desirable. Where possible, these should be multivalent consisting of bacterial, protozoal, and viral components. With respect to tick vaccines, effector mechanisms need to be characterized, so that vaccines for other tick species can be developed. In addition to this, novel delivery systems and novel antigens need to be generated for the anti-tick vaccines.

3. Conclusions

Diseases carried by ticks, flies, and mosquitoes will continue to exact a huge economic toll on livestock industries worldwide (Mekonnen et al., 2002). Control of these pests primarily rests on the use of chemicals, either applied directly to the animals or to the environment. Major problems associated with this include: the development of resistance to the chemicals, issues around the residues in animals and the environment, and their undesirable effects.

Whilst new technologies, such as the development of vaccines both against the insect pest in some cases or the disease they transmit in others and genetic engineering, hold out some hope for the future; these are not sufficiently well advanced to permit wholesale application.

For the foreseeable future, we must conserve what we have and use it in combination with all the principles of IPM: namely strategic and focussed treatments of animals, environmental control of breeding sites, disease management (including the principles of enzootic stability), interference with reproduction (SIT), modification of the vectorial capacity and resistant breeds. Research efforts must go towards developing viable vaccines against both diseases and the insect vectors, and the genetic modification of insects.

Governments, particularly in developing nations, must also develop effective policies that ensure sustainable service delivery and market development.

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