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Factors in the success and failure of microbial agents for control of migratory pests

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Abstract

Microbial control agents generally kill insects more slowly than chemical pesticides, and fast-moving migratory pests may not at first sight appear to offer the most promising targets for microbial control. Operators responsible for control may need to have recourse to chemical control agents. Nevertheless, there are many occasions when pests breed and feed outside the crop and a microbial control agent can be used. Similarly, immature stages may cause little damage and early treatment in the crop can avoid damage. Microbial control agents are particularly likely to be favoured if the pest breeds in a conservation area, and if a publicly-accountable agency is responsible for control.

Other key points of importance are the IPM context, in particular detection, planning and forecasting of outbreaks and the role of natural enemies.

With these points in mind, we identify several locust and grasshopper systems where microbial control is becoming established; additionally, Sunn pest of wheat and Armyworm are identified as promising situations for microbials.

Introduction

Migratory pests are perhaps the agricultural pests which raise the most public concern; biblical references to locusts aside, media attention is often focused on invading locust swarms; persistent attacks of leaf, stem or fruit feeding insects may be of much greater economic consequence while failing to attract the same attention.

Because migratory pests invade a farmer's crop from outside, often from fallow ground, responsibility for the control of migratory pests has often been assumed by governments and organisations acting in the common good. In some cases these organisations are financed by the farmers concerned, but very often control is free of charge to the farmers. This can have obvious drawbacks in that the extent of treatment depends only on the voice of the farmers affected, which may bear no direct relationship to potential economic loss. On occasions, publicly funded plant protection services do attempt to recoup some or all of their costs from those benefiting by the service.

We will discuss details on a case-by-case basis, but in examples where pest breeding occurs some distance from the crop, there may be opportunities for microbial control. Often the pest is in an immature stage; even when feeding on the crop, there may be time for a microbial agent to work before economic damage is inflicted. Where control is taking place outside the crop, the extra burden of detecting infestations may be placed on the plant protection agency. Furthermore, not all pest infestations will build up to damaging levels, and prediction becomes another function of the agency.

Determining the values of the key decision makers in pest control is an important facet in understanding when a microbial control agent is likely to be accepted. In the case of migratory pests controlled by public agencies, these agencies may be highly sensitive to public opinion and pressure groups, and may select a 'green' control agent.

The principal benefit of microbial control agents, that of leaving natural enemies alive and continuing to impact on pest populations, needs to be considered. Much more experimental work in this area is needed to confirm the low impact of microbial agents on natural enemies.

One other aspect of experimental work needs attention. Most migratory insects have complex behavioural patterns, making small scale experiments on the efficacy of microbial agents very difficult. Cage experiments are not acceptable as cages interfere with insects' thermoregulatory behaviour and can lead to over-estimation of efficacy; conversely in small field experiments, impact can be underestimated as treated, infected insects either leave the plot, or are swamped by invading untreated insects.

Finally, it is important to recognise that even the most environmentally aware and well-organised pest control agency will on occasion be faced with situations which get out of control. This may be because an infestation has gone undetected, or because of the failure of a control operation. In these cases, operators must have access to fast-acting and reliable chemical pesticides in order to avoid any loss of credibility. Total control failure is worse than the failure of a microbial control agent.

Case studies

It is probably premature to talk of definite successes in microbial control of migratory pests. In several of our examples however, commercial producers are producing for a market they believe to be profitable, and the key decision makers are convinced of the need and efficacy of a microbial product. Success will only be defined as the product either succeeds or fails over the years.

Brown locust in South Africa

The Brown locust (*Locustana pardalina* (Walker)) has its outbreak area in the semi-arid Karoo area of South Africa and southern Namibia. This locust has the highest outbreak frequency of any of the world's plague locusts and there have only been 5 years in the past 50 years when no control campaign was mounted in the Karoo. Before the 1940s, when effective control measures (organochlorine BHC) became available, Brown locust swarms used to regularly escape from the Karoo recession area and threaten food security in nine southern African countries up to the Zambezi river.

The locust is a certified pest in South Africa. Land owners are legally required to report outbreaks and the government is compelled to control these locusts. This law dates back to 1910. Farmers assist in the control operations and are reimbursed a mileage allowance for their involvement.

Current control strategy is to control outbreaks within the Karoo before swarms can migrate to the grain producing areas in the Free State and North-West Province and in the neighbouring countries. Although locusts do damage to grazing in the Karoo and compete with sheep for fodder, the main aim is to keep swarms out of the cropping areas and in this regard the South African locust control organisation has been very successful. Locust targets are controlled by the spot application of synthetic pyrethroid insecticide (deltamethrin UL) to roosting hopper bands and fledgling swarms. However, the repeated application of broad-spectrum insecticides in the unique Karoo biome is being increasingly questioned by conservationists and landholders.

Thus the essential elements are in place. The pest is breeding and feeding far from the areas where it causes economic damage, so speed of kill is principally of concern to the operators who wish to be certain that their work has been satisfactorily completed. The beneficiaries of the treatment are poor and entitled to receive government assistance, in this case in the form of pest control. And finally, there is very strong pressure for a non-toxic product, both from conservationists and the sheep farmers.

The company Biological Control Products (BCP) of South Africa, a small specialised company with existing expertise in production of microbial products, is producing the *Metarhizium anisopliae (flavoviride)* var. *acridum* strain IMI 330189, developed by LUBILOSA (LUtte BIologique contre les LOcustes et SAuteriaux) (Lomer *et al*. 1997, Bateman 1997) for this purpose, and has submitted a registration dossier to the South African authorities. As part of the registration dossier, tests on Cape Honey Bee were submitted, along with many field trial results (e.g. Price *et al*. 1997).

Grasshoppers in West Africa

The grasshoppers of Sahelian West Africa present a much less clear picture than that of Brown Locust, but nevertheless, Natural Plant Protection (NPP) of France has taken up production of *Metarhizium* as developed by the LUBILOSA project for this purpose. Several different pest species are involved in this zone, which extends across Senegal, Gambia, Mali, Burkina Faso, Niger and Chad. In order to simplify the discussion, we will focus on the migratory species *Oedaleus senegalensis*, and the sedentary species *Hieroglyphus daganensis*. Other migratory species in the zone are Desert and Migratory locusts (*Locusta migratoria*), but these are only of occasional importance; Desert locust is discussed further below.

The non-migratory species consist of a complex of 8 or 9 species, including *Kraussaria angulifera*, *Kraussella amabile*, *Hieroglyphus daganensis*, *Diabolocatantops axillaris*, *Cataloipus fuscocoeruleipes*, *Pyrgomorpha cognata* and other species in varying proportions in different years. However, all appear to be susceptible to the *Metarhizium* isolate IMI 330189 tested by LUBILOSA, so the comments made will apply to all the species.

Oedaleus senegalensis frequently has 3 generations in a year, hatching with the first rains in May or June. Subsequent generations may breed *in situ* or migrate some distance in search of suitable oviposition sites. A simplified schema has the second and third generation following the rains northwards; if all generations breed successfully, this can lead to a massive southwards migration of adults in September, just at the time of maturation of the millet crop. Real life is more complex, and it is seldom possible to know much about the movement of the adult grasshoppers or to predict the arrival of the southward-moving swarms (Cheke 1990, Launois & Launois-Luong 1988). This final generation frequently oviposits in the millet fields themselves, which brings an added hazard the following year when young nymphs may hatch and destroy the millet seedlings just as they are germinating.

The sedentary grasshoppers generally hatch and feed near the crops. Their preferred oviposition sites are under bushes or clumps of vegetation, and the first two or three instars generally feed nearby before moving to the crop. Local knowledge of the breeding habits may sometimes be muddled; although most farmers distinguish 8 or 9 species, they are principally aware of the arrival of migratory *Oedaleus* ‘on the wind’ and fail to appreciate the local breeding habits of the non-migratory species. This can be rapidly corrected by demonstration.

Farmers have used a variety of traditional control techniques, such as using smoke to repel arriving swarms, and driving migrating hopper bands into ditches. Chemical pesticides are widely held to be more effective, and voluntary village brigades carry out applications of donor-supplied chemicals. However, western donors are heavily criticised for supplying chemicals, and only one donor continues to provide pesticides.

As well as village brigades, other agencies also are involved. In Niger, the plant protection service (DPV) carries out aerial applications over many thousands of hectares. In Mali, non-governmental organisations (NGOs) have largely taken over the central government responsibility for grasshopper control.

Thus overall, we are dealing with a complex situation, but from which we can highlight the following points. Firstly, the pest insects, in their immature stages, can be tackled outside the crop; treatment of immature stages within the crop is also possible as millet withstands considerable leaf feeding damage. Secondly, aid is being provided to the beneficiaries, and the donors would prefer to fund a ‘green’ product. Thirdly, infrastructure is in place to distribute and apply a microbial product. The principal challenges remaining to wider scale implementation are: (i) ensuring continuity of donor funding from chemical products to the microbial; (ii) ensuring an effective detection and treatment strategy.

Desert locust

The Desert locust, *Schistocerca gregaria*, is the most widely known and feared of the locust pests, and represents the most complex situation of all the migratory insects. The breeding grounds are generally concentrated in the Red Sea coastal area; when plagues occur, a vast area from Mauritania to India can be invaded, and breeding may occur in any of these places. Thus any rational control strategy must focus on the outbreak breeding areas, and this is the objective of the FAO EMPRES (Food and Agriculture Organisation of the United Nations Emergency Prevention System for transboundary animal and plant pests and diseases) programme. Until the major plagues of the early 1980s, there had been nearly 30 years free of plagues. However, it was never clear whether this was a purely coincidental climatic effect, or whether the regional operations were being highly effective. When the plagues did start again in the 1980s, it was clear that neither the organisations nor the tools were appropriate to the control operations. During the inter-plague years, funds for research and surveillance had diminished, and much infrastructure and expertise had been lost; furthermore, the most effective tool, the persistent organochlorine pesticide Dieldrin was no longer accepted for use.

The FAO has a pesticide review panel, to which pesticide manufacturers submit dossiers on products considered suitable for locust control. The panel prepares a list; these are the products favoured for locust control, although the EMPRES programme retains a research capacity to investigate new options. The LUBILOSA *Metarhizium* mycopesticide is on the list of products for locust control, and wider scale testing can be expected within an integrated framework. However, for any product, the key to successful locust control lies in the scouting and surveillance operations.

Thus with Desert locust we have a situation where the pest breeds far from the crop, and the immature stages can be targeted; research is increasingly demonstrating the importance of natural mortality (Wilps 1997). Surveillance and forecasting systems are improving (Cressman 1997). Because public funding is being used, an environmentally sound product is preferred. Although control operations take place far from human habitation and agriculture, many of the desert environments are considered rather fragile and *Metarhizium* should meet many of the requirements for use in such zones.

One of the problems with implementing a microbial control agent against Desert locust is the infrequency of outbreaks; since 1969, major swarms have developed only in 1986–1989 and 1992–1994 (Pedgley 1987; Showler 1991, 1995). A small producer cannot rely on regular demand for the product, and although the shelf-life of fungal products can exceed 18 months under ideal conditions, locust control operators are accustomed to storing chemical pesticides for several years under primitive conditions.

Finally, with Desert locust more than with any other pest, the back-up availability of fast-acting chemical pesticides is essential.

Other locusts and grasshoppers

The particular features of the ecology of some of the principal locust and grasshopper pests world-wide are summarised in Table 1, with a few comments on their potential for the implementation of microbial control. See Krall *et al*. (l997) and Lomer *et al*. (1999) for recent reviews.

Sunn pest

Sunn pest is a complex of 4 or 5 species of pentatomid; the principal pest species is *Eurygaster integriceps*. Sunn pest attacks wheat and to a lesser extent barley throughout South-East Europe and the Near East (Turkey, Syria, Afghanistan, Iraq, Iran and Romania), sucking the sap from stems and the milk from grain. Very low pest levels can inflict considerable damage;

Table 1. Special features of the ecology of some of the principal world-wide locust and grasshopper pests

Species	Distribution	Special feature
Variegated grasshopper, *Zonocerus variegatus*	West and Central Africa	Slow moving, highly susceptible to particular isolates of *Metarhizium*
Elegant grasshopper, *Zonocerus elegans*	East and southern Africa	Slow moving, highly susceptible to particular isolates of *Metarhizium* (probably)
Red locust, *Nomadacris septemfasciata*	Southern Africa	Lives in wetlands, good prospects for recycling; susceptible to LUBILOSA *Metarhizium*
Migratory locust, *Locusta migratoria*	Madagascar	Outbreaks in conservation areas
Tree locust, *Anacridium melanorhodon*	Sudan, Kenya	Feeds on acacia trees; high economic threshold
Moroccan locust, *Dociostaurus maroccanus*	North Africa, southern Europe, CIS states	Pressure for green product
Melanoplus sanguinipes	America and Canada	Have to follow *Nosema* and *Beauveria*
Australian plague locust, *Chortoicetes terminifera*	Australia	Excellent prospects; predictive modelling advanced, *Metarhizium* product field tested.

one insect may destroy 2 heads per day, and flour quality is reduced. Economic loss levels are much less controversial than for locusts, and accurate estimates of total pesticide expenditures are available (Miller & Morse 1996).

Sunn pest overwinters in mountain sites, far removed from farmers' fields; it descends in spring, feeds, mates and oviposits in or near the wheat fields. The eggs hatch and the young nymphs feed on the wheat until mature, then migrate to the mountains to aestivate, moving to lower sites to hibernate. Natural enemies include egg parasitoids (*Trissolcus* spp.) and infections of *Beauveria bassiana* at the overwintering sites. A great deal is known about the pest ecology and population dynamics. Of particular importance are water relations and timing of planting; adult Sunn pest must build up fat reserves to survive the winter and oviposit. If the wheat crop matures before the Sunn pest, oviposition success the following year is low (Donskoff in Miller & Morse 1996).

Current control operations are by publicly funded aerial applications of chemical pesticide, and these occur in Turkey, Romania, Syria, Iran and Iraq.

So we have a situation with public funding for pest control, but as yet little pressure from environmentalists to convert to a 'green' product. In particular, the funding comes directly from national governments of countries with weak environmental awareness. Although the pest is to be found outside the crop, the best moment for intervention with a microbial control product is not clear; it could be at the overwintering sites, on the newly arriving adults, or on the maturing nymphs. The role of the egg parasitoids could be greatly enhanced by the use of refuges and reducing the utilisation of chemical pesticides.

Armyworm

The Armyworm, *Spodoptera exempta* is a noctuid moth which occasionally builds up to damaging levels in the East African grasslands. At high population levels, the larvae form devastating bands which may leave the grasslands and attack smallholdings. A trap network is operated by the governments of Tanzania and Kenya.

A virulent NPV baculovirus has been known for many years, and there are reports of traditional use of this virus by Maasai herders. Given the virulence and persistence of the virus, it is likely that a highly effective control operation based on this microbial control agent could be implemented.

Other situations

In the invitation to this symposium, we were asked to talk also of failures in control. To me, there is no such thing as failure, only challenges for further work which may or may not be worthwhile at the present time. Technical efficacy may be improved through the use of new strains, production methods, formulations, application strategies. Socio-economic factors, in particular the importance attached to environmental considerations, can change with time. And of course, economic factors, particularly production costs, vary enormously throughout the world and may tumble with increases in scale, or when production is transferred from a research organisation to the private sector.

The entomophthoralean fungi always attract attention because of their capacity to cause spectacular epizootics. Research at IITA on *Entomophaga grylli* against *Zonocerus variegatus*, while investigating production in artificial media and the climatic conditions associated with outbreaks, has not so far indicated any positive way to make use of this fungus; by contrast, a Brazilian isolate of *Neozygites floridana* has recently been released in Benin against the cassava green mite, *Mononychellus tanajoa* with good prospects for success similar to that achieved with Australian *Entomophaga praxibulli* for grasshopper control in the US.

The protozoan *Malamoeba locustae* was investigated as a microbial control agent for locusts in Kenya (Raina 1992). However, although causing good laboratory mortality, *Malamoeba* was never effective enough for field testing.

Another protozoan, *Nosema locustae*, was field tested for many years, and produced commercially by Evans Biocontrol for several years. It was also field tested in Africa. After several years of production, sales were poor and production was discontinued. However, as discussed in a recent review by Johnson (1997), large-scale applications are carried out in China (Yan *et al*. 1996), and current collaborative research by IITA and Agriculture Canada is following up the longer-term effects of the 1988 field trial in Mali. Commercial products may go out of production, or fail to meet sales targets for a variety of reasons having little to do with the utility of the product. With the existence of *Metarhizium* as a faster-acting control agent, it may well be time to revisit the use of *Nosema* as a complementary persistent microbial control agent.

In the case of *Beauveria*, Inglis *et al*. (1997) have demonstrated that some strains were limited in their efficacy against grasshoppers by environmental conditions, because of grasshoppers' capacity to thermoregulate to temperatures above the temperature tolerance range of the fungus.

One further feature of the North American grassland situation has been the development of an IPM model, HOPPER, which incorporates various management practices and economic data (Berry 1995). Whilst not excluding biological control options, the use of this model appears to have reduced control costs without triggering an increased demand for biological products.

Conclusion

Although developing a microbial control product for migratory pests poses enormous challenges at the experimental stage, effective microbial products can be uniquely suited to the exigencies of controlling migratory pests. The particular features of migratory pests favourable to microbial control are: (i) that feeding and breeding takes place outside the crop, often in conservation areas where high natural mortality can be expected to take place; (ii) as there is often public funding for control, high environmental values are involved in the purchasing decisions. The principal challenges are: (i) that operators need assurance that their treatments have been successful; (ii) that the product may need to be stored for long periods. A fast-acting chemical treatment should be available in case of failure of either the microbial agent itself or of the detection process.

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