SOME ASPECTS OF BIOLOGICAL CONTROL OF CRAWLING INSECT PESTS IN THE URBAN ENVIRONMENT

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INTRODUCTION

If we compare the achievements of biological control of flying and crawling pests of health importance in urban environments, we have to admit that the biocontrol of bloodsucking dipterans is far ahead of biocontrol of pests such as cockroaches, ants, termites, bedbugs, assassin bugs etc. The reason for this is sometimes only a lack of adequate knowledge of specific, potent, easy to cultivate, and safe agents applicable in the close vicinity of man. Moreover, the agent should not be more repulsive to the inhabitants than the pest itself. Unfortunately, in urban environs some synanthropic arthropods are fully disassociated from their natural enemies (e.g. domestic cockroaches, Pharaoh's ants). Thus,pest populations are regulated primarily by abiotic and density-related factors rather than by coevolved guilds of pathogens and parasitoids (Schal and Hamilton, 1990).

Following the groups of organisms from where effective biological agents usually recruit e.g. viruses, Rickettsias, bacteria,fungi, protozoa, nematodes and predatory/parasitoid insects we can conclude that only few agents have been successfully employed in crawling insect biocontrol. Nevertheless some organisms seem to be promising although they require further laboratory and field research and application techniques development. This contribution is an attempt to briefly summarise current information about crawling pests, pathogens or parasites in urban environs with the hope that it will provoke further research activities which might lead to the development of effective methods of biocontrol.

Viruses

Many insect species are vectors of viruses which cause serious infections of plants,animals and man. But most of the viruses vectored by insects are not pathogenic to the vectors. On the other hand, there are few viruses which can be used for effective insect control. Since the eighties the nuclear polyhedrosis virus (NPV) has been used for *Heliotis* sp. control (Poinar and Thomas, 1984). Some viruses cause natural epizootics but such cases in crawling insects seem to be rather rare. Suto (1979) and Suto *et al.* (1979) isolated a parvorvirus of *Densovirus* group from the smoky brown cockroach *Periplaneta fuliginosa* and when introduced, the virus caused a natural epizootic with 80% kill of the late instar nymphs in a breeding cage. It is evident that the high entomopathogenous potential of viruses (e.g. baculoviruses) warrants further research.

Rickettsias

There are some Rickettsias which are considered essential for development and reproduction of the host e.g. *Symbiotes lectularius* in mycetomes of the common bedbug (*Cimex lectularius*) and *Blattabacterium* sp. in mycetocytes of cockroaches. Rickettsias, belonging to the genus *Rickettsiella* are pathogenic to their insect hosts (Poinar and Thomas,1984). The role of compatibility of the symbionts with their hosts and possible change into pathogens for their hosts has not been studied in crawling insects, but it is well known in mosquitoes(*Wolbachia pipientis*). Specific Rickettsias are also known in fleas and lice. But all Rickettsias are considered as at least potentially dangerous to humans and their use in biocontrol is therefore improbable.

449

Bacteria

As with other groups of insects, bacteria are associated with crawling insects externally and internally. The role of cockroaches as vectors of bacteria which cause serious human diseases is very well known. Cockroaches contract the bacteria during the search for food. However no apparent killing effect of contracted bacteria on the vectors has been recorded. Many genera of obligatory anaerobic intestinal bacteria have also been diagnosed. (e.g. Bracke, 1977).. A true cockroach bacterial pathogen still has to be found.

In termites, guilds of symbioic intestinal bacteria are highly beneficial for their hosts, but a specific selective bacterial pathogen for termites has not been found.

Contrary to the phenomenal effect of true bacterial pathogens such as *Bacillus thuringiensis* or *B. sphaericus* for lepidopteran catepillars or dipteran larvae, these bacteria have not yet found a major role in crawling insect control. In literature only rare remarks dealing with possible pathogenic effect of *Bacillus* spp. on crawling insect can be found. Ulewicz (1975) and Sandhu and Varma (1980) reported moderate to complete kill of cockroaches fed on food mixtures containing Bt products. The larvicidal effect of beta exotoxin and no larvicidal effect of delta endotoxin applied into feeding medium for the oriental rat flea (*Xenopsylla cheopis*) was observed by Maciejevska *et al.* 1988.

Beside *B. thuringiensis* and *B. sphaericus*, also *Serratia entomophila*, whose range of activity is not well known, should be tested against ants or roaches. For crawling insects, including cockroaches,flea larvae, ants and termites, the preparations of *B. thuringiensis* containing beta exotoxin are active, and formulations with non-reduced content of exotoxin should be tested.

Fungi

The relations of fungi and insects range from true symbiotism (e.g. in termites) to a full pathogenic effect. More than 400 species of fungi are entomopathogens. True pathogenic fungi which eventually destroy the insect host attack a variety of terrestrial and aquatic insects (e.g. in mosquitoes *Culicinomyces spp* attack mosquito larvae and *Entomophthora spp.* attack adults). In contrast to bacteria and viruses that pass through the gut wall from contaminated food, fungi have a unique mode of infection. They reach the hemocoel through the cuticule or possibly through the mouth parts. Ingested fungal spores do not germinate in the gut and are voided in the feces. Infection therefore results from contact between a virulent infectious inoculum and a susceptible insect cuticule, followed by germination, penetration of the germ tubes through the integument and finally spread of the pathogen throughout the host tissues (Ferron, 1981). Many entomopathogenic fungi overcome their hosts after only limited growth in the hemocoel, so toxins are presumed to cause host death. Of the known fungal toxins, the destruxins, beauvericin and Basianolid are poor insecticides, the most active being tolipin produced by *Tolipocladium* spp fungi (Weiser and Matha, 1988). Also cyclosporin, produced by the same fungus is efficient as an insecticide and so is avermectin in humoral administration for lice and bugs attacking livestock.

With cockroaches some fungal infections have been observed but without apparent lethal effect (Richards and Smith 1956). More recently, a lethal infection from a hemocoelic yeast-like fungus has been reported for the German cockroach, *Blattella germanica* (Archbold *et al.* 1986,1987). Verrett *et al.* (1987) observed a similar infection in an American cockroach, *Periplaneta americana* colony and identified the causative yeast as *Candida*. But consideration of the possibility of using the fungus in biological control of the cockroach seemed to the authors to be premature because sibling species of *Candida* are human pathogens.

Some entomopathogenic fungi are commercially produced and used in agruculture or horticulture, *Metarhizium anisopliae* and *Beauveria bassiana* are the best known. Actual progress in application of *B. bassiana* and *M. anisopliae* for control of grubs and locusts also reflects application in the control of termites (Haenel and Watson 1983) and fire ants(Jouvenaz, 1990). To the author's knowledge *M. anisopliae* is the only fungus which is due to be commercially employed in cockroach control (Bio-Path® control chambers produced by EcoScience).

Protozoa

There are some symbiotic protozoa which are highly beneficial for insects e.g. termites or wood roaches and if they are absent, cause serious damage to the hosts. Some flagellates change from symbionts to pathogens e.g. *Blastocrithidia triatomae* in triatomine bugs (Schraub, 1990). Other protozoa are seemingly innoculous for their insect carriers but cause serious diseases in man and domestic animals (*Trypanosoma*). Many protozoa have been diagnosed in cockroach guts and some of them have "inherited" their names e.g. *Gregarina blattarum*, *Endamoeba blattae*, *Lophomonas blattorus* or *Hexamita periplanetae*. In *P. americana*, Khairul and Paran (1978) observed a non-debilitative effect of those on the host. But in some stored product pests, some Gregarinida, Coccidia and Microsporidia generally do produce chronic diseases that reduce population growth by increasing mortality, slowing development and lowering fecundity especially in populations under stress (Arbogast, 1984).

Some of the Apicomplexa series of organisms are known as pathogens of roaches, fleas or bugs, but there is no progress in studies of these pathogens as possible biocontrol agents. Among Microspora the most common pathogens of crawling insects can be found. Recently a microsporidian, *Nosema pulicis* in *Ctenocephalides canis* and *Archaeopsylla erinacei* was complemented with two important descriptions: *Pulicispora xenopsyllae* (Vedmed et al.,1991) and *Nolleria pulicis* (Beard et al., 1990a), both with prospective potential in production and application for treatment of burrows and nests for biological control of fleas. In a study of three fleas from Florida, microsporidia were reported in 6% animals (together with buculoviruses, amoebae, flagellates and gregarines), but those microorganisms did not cause real pathogenic effect (Beard et al., 1990b). Microsporidian infections are known from fire ants, with a *Thelohania* and *Burenella dimorpha* as main pathogens and possible candidates for field application (Jouvenaz, 1983). Identical perspectives are in some microsporidia for termite control (Kalavati, 1976). A further contribution to the gallery of prospective pathogens of crawling synanthropic insects (e.g. cockroaches) is *Coelosporidium tangae* (Purrini et al., 1988). Experiences with application of *Nosema locustae* against grasshoppers and crickets and of *N. algerae* for mosquitoes may support the effort to use microsporidia in baits for the control of other insects.

Nematodes

The literature includes over 3,100 natural associations between insects and nematodes, involving 11 orders of nematodes and 19 orders of insects. Nematodes attack both terrestrial and aquatic insects and occur in all host-stages except the egg (Poinar and Thomas, 1984). Quite large numbers of nematodes have been diagnosed in cockroaches, e.g. in *P. americana* at least 12 nematode species,representing 9 genera,have been reported in various combinations from this host (Strand and Brooks, 1977). Adamson and Noble,(1992) found 4 Oxyurid species in a colony of the American cockroach.

The facultatively parasitic rhabditoids from the families Steinernematidae and Heterorhabditidae, which are generally considered to be specific to insects, seem to be especially promising as bioinsecticides (Georgis, 1990). The only free-living stage of these entomopathogenic nematodes is the third-stage infective juvenile. Under natural conditions, this stage persists primarily in the upper layer of the soil, where it can survive for months until it finds a new host (Kaya, 1985). The nematodes cause death by vectoring the mutualistic bacteria, *Xenorhabdus nematophilus* into the hosts hemolymph, where the bacteria cause septicemia and rapid death (Woodring and Kaya, 1988).

It is the genus *Steinernema(= Neoaplectana*) which has seemed to be the most promising for biocontol of crawling insects such as cockroaches, termites, crickets etc. and even ticks. The potential for biocontrol using *S. carpocapsae* has been covered in literature most often.

In laboratory conditions, Dutky at al. (1956) exposed three species of cockroaches to *S. carpocapsae*, and found that *B. germanica* was only slightly susceptible, *Nauphoeta cinerea* was very susceptible, and *P. americana* was highly resistant to the agent. But the methods by which the authors experimentally exposed the cockroaches to the nematodes were not outlined. In contrast, Zukowski (1984) found that 100, 200, and 400 *S. carpocapsae* nematodes per petri dish killed 76, 88, and 96% of German cockroaches, respectively. More recently Kohler et al. (1992) placed 500,000

nematodes ("All" strain, provided by Biosis, Palo Alto, Calif.) on filter paper in a petri dish or the pad of a bait station and exposed late-stage nymphs and adults of five cockroach species. German (*B. germanica*), brown-banded (*S. longipalpa*), Oriental (*B. orientalis*) and smoky-brown (*P. fuliginosa*) cockroaches died within one day after placement in the petri dishes. American cockroaches (*P. americana*) died after 1-5 days depending on the stage or sex of the roaches. The LT_{50} for *S. carpocapsae* for non forced (bait) exposure were 3.25, 4.13, 9.86 and 11.38 days for brown-banded, German, Oriental, and smoky-brown cockroaches, respectively. The nematodes exposed in baits were ineffective in killing American cockroaches. The relative order of the LT_{50}s after forced and nonforced exposure to *S. carpocapsae* was inversely related to the moisture of their preferred habitats. Corpus and Sikorowski (1992), despite achieving 93% kill of the brown cockroach (*Periplaneta brunea*) with 300,000 infective juveniles of *S. carpocapsae* per 50 cm^3 sand, pointed out the main problem of maintaining a high level of moisture especially in larger treatments arenas.

With termites the use of entomopathogenous nematodes seems to be even more complex than with cockroaches. Mix (1985, 1986) cited R. Beal of Wood Product Insect Lab., Gulf Port, Mississ. who stated that nematodes were effective in killing termites in the laboratory but not in foraging and field tests and suggested that their widespread use might be limited by temperature and moisture. Later Mauldin and Beal (1989) studied the efficacy of nematodes in preventing or eliminating eastern subterranean termites, *Reticulitermes flavipes*, in the laboratory and infestations of *Reticulitermes* spp. in the field using two strains (Breton and All) of *S. feltiae*, *S. bibionis*, and *Heterorhabditis heliothidis*. In the laboratory, after 9.5 weeks, termite survival rates in the nematode treated and in untreated controls did not differ significantly. In field studies, nematodes did not eliminate or control termites either in a situation of soil treatment under concrete slabs or in logs naturally infested with termites. Moreover, the authors did not consider three weeks of protection from termite damage for a wooden structure or product as acceptable – quoting the results which had been gained by Epski and Capinera (1988) by treating soil underneath it with 1×10^7 nematodes (*S. feltiae*) per m^2 against *Reticulitermes tibialis*.

Recently Drees et al. (1992) tested, under laboratory conditions, the pathogenicity of infective juveniles of selected *Steinernema* spp. and *Heterorhabditis* spp. toward developing and reproductive stages of the red imported fire an *Solenopsis invicta* and concluded that a soil drench of *S. carpocapsae* showed potential as a control method for the red imported ant. Colony relocation after nematode treatment could limit overall efficacy unless application techniques are developed to overcome or take advantage of the movement.

Parasitic Hymenoptera

Between 1940–1960, many reseachers evaluated the potential of parasitic Hymenoptera as biological control agents of cockroaches and reported parasitoid biologies, natural and experimental parasitation rates and host associations. Roth and Willis (1960) reviewed the early work on cockroach enemies. Subsequent research has concentrated on those parasitoids that appeared promising for cockroach control. Quite recently Lebeck (1991) has fully reviewed the current knowledge of the subject citing an astounding number of 75 references.

Most species of Hymenopterous enemies of cockroaches are parasitoids of their oothecae, but members of Ampulicidae, and other Sphecoidea are predators of cockroach nymphs and adults. *Ampulex compressa* stings its prey twice then leads the partially-paralyzed, submissive and lethargic cockroach to a previously located cavity.

The evaniids (ensign-wasps) are solitary parasitoids of cockroach oothecae, but they are relatively large (5–10 mm) and conspicuous-looking and sometimes arouse more complaints then the pests when found at windows in cockroach-infested homes. They parasite all important cockroach species except the brown-banded cockroach, *Supella longipalpa* and the German cockroach, *B. germanica*. Mass releases of evaniids e.g. *Evania appendigaster* or *Prosevania punctata* within buildings is improbable due to their size and wasp-like behaviour, but their *Periplaneta* and *Blatta* hosts can also be serious outdoor urban problems in areas such as sewer systems and trash dumps. These sites may prove ideal for releasing Evaniids (Lebeck, 1991).

Chalcidoids, which parasite cockroach oothecae, are gregarious and small (1–2 mm) and usually inconspicuous to inhabitants. Gregarious behaviour and female-biased sex ratio mean a larger

number and greater proportion of females will be searching for host oothecae. In appropriate locations, *Aprostocetus hagenowii* (better known as *Tatrastichus hagenowii*) and *Comperia mercenti* have exhibited rather high rates of parasitism and thus show the most promise as a control agent. Mass rearing techniques are relatively easy (Hagenbuch et al. 1988) and parasitoid development is shorter than for Evaniids.

Naturally occurring populations of *A. hagenowii* have been found outdoors and indoors. Fleet and Frankie (1975) reported parasitism of *P. fuliginosa* at levels ranging from 22.2 to 84.2%, outdoors in College Station, Texas. From Texas and Lousiana Piper *et al.* (1978) reported parasitism of *P. americana* outdoors ranging from 46% for exposed oothecae to 73% of concealed oothecae. Narasimham and Sankaran (1979) found 16% field parasitism of *P. americana* indoors in India, indicating that *A. hagenowii* will enter homes from principal outdoor foci. Hagenbuch *et al.* (1989) reported inundative releases of *A. hagenowii* provided effective control (more than 95% parasitism of viable oothecae) in experimental chambers and could be used in combination with hydramethylnon baits to control *P. americana*. However, Narasimham (1984) reported that *A. hagenowii* was outcompeted by *A. asthenogmus* in inoculative releases in attacking *Periplaneta* spp. in Bangalore ,India and that both primary parasite populations were reduced by the obligatory hyperparasite *Tetrastichus* sp. A. (*T. miser* group).

Comperia merceti appears to be host specific for oothecae of *S. longipalpa*. Zimmerman (1948) noted that after the accidental introduction of the wasp in Hawaii,*S.longipalpa* was "practically wiped out" in some areas, and oothecal surveys showed parasitation could reach 100%. The first mass rearing and experimental releases of *C. mercenti* against *S. longipalpa* were attempted by Slater *et al.* (1980) on the campus at the University of California-Berkeley. During two years over 20,000 parasitoids were released indoors. *C. mercenti* successfully became established and was not offensive to people working in release areas. They suggested periodic augmentation of *C. mercenti* might increase parasitization rates which only reached a maximum of 19% in one location. Similar natural parasitization rates (19.5%) for *C. mercenti* were obtained by Narasinham and Sankaran (1979) during their oothecal survey in India. Coler *et al.* (1984) confirmed the need for inundative releases of *C. mercenti*,especially when *S. longipalpa* populations were low.

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