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"Integrated Protection of Stored Products"

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"Protecion Intégrée de Denrées Stockées"

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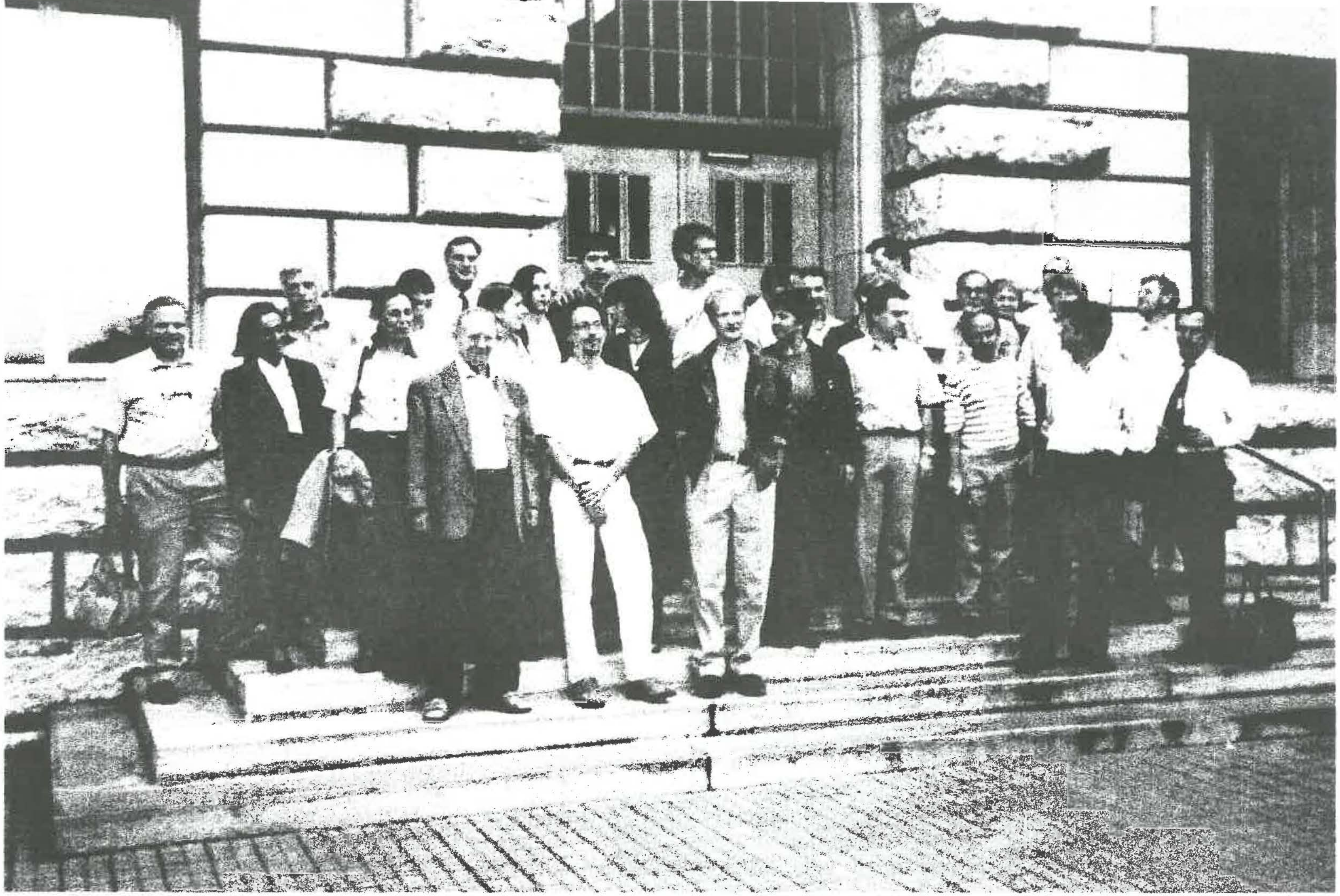

Photo: A. Levinson

INTRODUCTION

Agricultural products are not only attacked by various pests in the field but mankind has to defend harvested goods during storage, as well. Stored product protection today is dominated by the use of pesticides. However, there is a strong interest in the development of methods that help to improve workers´ and environmental safety, methods that help to avoid the occurrence of pesticide resistance, and minimize residue levels in treated products. For the vast variety of stored products, techniques are needed to avoid losses and to maintain product quality during storage and handling. In very different storage environments, potential pests need to be identified and studied and techniques have to be developed that help to prevent, detect and control these pests.

The IOBC/WPRS study group „Integrated Protection of Stored Products" met in Zurich, Switzerland, from August 31 to September 2, 1997. Short scientific presentations were accompanied by a tour through the laboratories of the Institute of Plant Sciences, Applied Entomology at the Swiss Federal Institute of Technology (ETH), an excursion to a local food producer using techniques of integrated pest management, and a film on parasitoids of stored product insect pests. The local hosts, Silvia Dorn and Felix Waeckers from the ETH Zurich, are thanked at this place for the perfect arrangement of the meeting and the warm and welcoming atmosphere we all enjoyed during these days.

The meeting attracted 37 participants from 12 countries. This volume reflects the presentations given during the event, two more manuscripts were sent by colleagues who were not able to attend the conference. I am grateful to Catharina Hild for her help in compiling these proceedings.

Over the last decade, an increasing scientific interest in biological control techniques could be witnessed. Nevertheless, to my knowledge this study group meeting was the first international conference on stored product protection dominated by presentations on biological control and monitoring techniques.

During the meeting it was agreed to change the fonner name of the study group „Integrated Protection of Stored Food Products and Other Commodities" into „Integrated Protection of Stored Products". The fonner convener of the study group, Giorgio Domenichini from Piacenca, Italy, was thanked for his work.

Cornel Adler, convener

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What is integrated stored product protection?

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ABSTRACT

The paper intends to outline the techniques and topics of integrated stored product protection. Differences between integrated plant protection in the field and stored product protection are described. Integrated stored product protection has been defined as a combination of methods to prevent, detect and control pest organisms by physical, biological, biotechnical or chemical means with the aim to keep product properties at an optimum during all processes between harvest (production) and consumption. Examples for such methods are mentioned. In order to reduce the application of toxic agents in stored product protection, methods that help to prevent pest infestations and monitoring techniques could be implemented more widely and improved according to storage type, product, etc. For the control of stored product pests, in some areas physical treatments like the application of heat or cold, controlled atmospheres or biological control can be an alternative to the use of fumigants and contact insecticides.

INTRODUCTION

The concept of integrated plant protection can be characterised by the following fundamental features (Freier, Burth and Palluth 1995):

1. a complex and sustainable approach
2. Inclusion of ecologicl demands and effects and
3. minimal use of chemical plant protection agents.

Even though this concept of was included into the German Plant Protection act in 1986 it was not readily applied into pratice by farmers. Freier et al. attribute this to the lack of exact demarcation from conventional plant protection or from good plant protection practice, watering-down the concept itself, and reducing its public acceptance. In the field of post harvest or stored product protection there is some similar discussion on how the principles of integrated pest management and integrated plant protection could be applied (Hagstrum and Flinn 1996, Reichmuth 1996, Schöller et al. 1997).

Stored products according to the German Plant Protection Act are harvested parts of plants, not altered or only altered by simple processes like drying, cutting or milling. In durable stored products mainly insects and mites can develop and these organisms are generally regarded as stored product pests. However, some of these species may also occur in commodities of animal origin and even mixed food products or animal feed. Hygienic or urban pests like ants, roaches or flies, that may contaminate stored products with pathogens often live associated with true stored product pests in goods of this type.

The moisture content of a product is one of the main factors determining the spectrum of its potential pest organisms. This is illustrated for the example of wheat in table 1. Stored product beetles, moths, dustlice and mites, specialized to survive in the artificial and comparatively dry environment of a storage may attack these commodities and can lead to severe damage or even complete losses of the stored produce. These arthropods contaminate the stored goods. Webbings, excretions, frass, dead individuals, larval exuviae and feeding holes may soon render a product unsuitable for commerce. Moreover, these animals have the capability to thrive on dry goods without an external source of water. In a commodity suitable for their development they utilize the product moisture and produce the necessary additional quantities of water chemically by breaking down carbohydrates in the presence of oxygen. Provided a sufficient number of individuals is present in a stored product, such metabolic reactions and excretion cause a considerable increase in product moisture, carbon dioxide content and temperature. This may give rise to the development of fungi like *Aspergillus* spp. or *Penicillium* spp. which augment to moisture content and temperature as well as product deterioration. In some cases the stored goods may even be contaminated with mycotoxins or antibiotics.

Differences between integrated plant protection in the field and stored product protection

Integrated plant protection in the field can be distinguished from the protection of harvested products in a storage environment by the following points:

1. While in a living plant the attack of economically unimportant parts may be tolerated or losses may be compensated by additional plant growth, losses in stored products always mean financial losses.
2. Pest populations in the field may be destroyed by adverse weather conditions or natural antagonists while pests once established in a stored product are largely protected by the storage structure and the stored product itself. If present in sufficient numbers, stored product pest arthropods may influence temperature and moisture conditions to their favor and multiply rapidly leading to a deterioration of the stored product.
3. The factors 1.-2. reduce in stored product protection the economic threshold levels, i.e. the levels where economic losses due to infestation balance the costs for a treatment, to very small values. If stored products are directly turned into food like in the case of flour, nuts, pulses, teas, spices or dried fruits, there is mostly a zero tolerance for pests due to consumer demands and food regulations.
4. The process of harvesting, threshing, cleaning, drying procedures, product movement during transport, but also the absence of water and other adverse conditions in a storage generally lead to the expulsion or destruction of field pests. This allows in many cases to start stored product protection by preventing the immigration of stored product pests into the product.

Definition of Integrated Stored Product Protection

The German Plant Protection Act from 1986 defines integrated plant protection as

„... a combination of methods in which with particular attention being paid to biological, biotechnical, plant-breeding and cultivation-related measures, the use of chemical plant protection substances is limited to the necessary extent“.

The European Union (1991) defined integrated control as „the rational application of a combination of biological, biotechnical, chemical, cultural or plant-breeding methods whereby the use of chemical plant protection products is limited to the strict minimum necessary to maintain the pest population level below those causing economically unacceptable damage or loss.“

Reichmuth (1996) described integrated pest management in stored product protection as comprising „hygiene, technical, technological and biotechnical methods, physical control, biological control and chemical control. These methods should be harmonised in a way granting highest priority to the protection of the human health as well as the environment. Moreover, commercial policy is a possible further element of IPM.“

If the aspect of quality maintenance is added to this definition, integrated stored product protection may be seen as a combination of methods save to the environment and human health that help to prevent, detect and control pest organisms by physical, biological, biotechnical or chemical means with the aim to keep product properties at an optimum in all processes between harvest (production) and consumption. Pest prevention, early pest detection and pest control are the three columns of integrated stored product protection (figure 1) and idealistically, investments in the former two help to reduce the frequency and volume of pest control actions.

Pest prevention

Assuming that the processes of harvest, drying, threshing, transportation and other types of product handling have reduced arthropod pests to a minimum at the beginning of storage, it is most important to prevent the invasion of specialized stored product pests by a good structural design (Reichmuth 1996) and storage conditions unfavorable for pest development. This aspect needs to be taken into account already in the machine design of combined harvesters, grain elevators and the farmers storage facilities. Storage enclosures (rooms, silo bins, etc.) on the farm, in a mill or any other location between producer and consumer should have even surfaces without cracks or crevices in order to avoid hiding places for insects and mites. Smooth surfaces will also facilitate hygiene measures and empty room treatments. An industrial hoover used to remove dust and spilled products is an important tool for pest prevention. Gaskits of doors and windows should be maintained and checked at regular intervals. Moreover, windows and other openings may be rendered insect-proof by covering them with a fine wire mesh gauze. A good storage management will take care that products of a given type that are first in will also be first out of the storage. In order to avoid condensation problems in bulk products, lots of different temperatures or moisture contents should never be mixed. Extremely long storage periods should be avoided if possible, or special measures like hermetic anoxic storage or very low storage temperatures could help to maintain product quality for prolonged storage periods.

As long as the temperature in the storage is kept below 13°C most insects will not develop. But even in situations where such a cold storage cannot be maintained it may be worthwhile lowering product temperatures by improved insulation to solar irradiation and ambient air or electrical cooling because each degree less reduces the risk of mass development of pests (see table 2).

Packed products may be attacked by stored product pests during transport, during storage in warehouses, on the shelf in a supermarket, or within the consumers home. Moths usually cannot enter into the product but frequently lay their eggs onto the surface of cardboard boxes or bags. In most cases, the hatching tiny egg larvae with a head capsule diameter of less than 0.15 mm have no difficulty to enter the product because the seals of cardboard boxes, paper and plastic bags and other packing materials leave enough space.

Pest detection

In case pest prevention fails it is important to detect an infestation as early as possible. Visual inspection has to be carried out in regular intervals and the use of pheromone and food lure traps may help to detect a source of infestation before significant damage has occurred and before the infestation has spread to other goods. In the short-lived stored product moths mature females lure the male copulation partners over long distances by the release of sex pheromones. Even though each moth species has its own specific bouquet of odors males of *Plodia* and *Ephestia* (*Cadra*) can be attracted by one substance that is a major compound in all pheromones of the pyralid family: (Z,E)-9,12-tetradecadienyl acetate. This substance is utilized in pheromone traps commercially available for these moth species today. While the short-living moths release sex pheromones, from most stored product beetle species only aggregation pheromones are known that are used to attract conspecifics of both sexes to a food source. Aggregation pheromones are much less suitable for trapping because they are not sufficiently attractive to an insect already feeding in a product (Plarre 1994). Best results with aggregation pheromone-baited traps may be expected in combination with a food lure in empty storage rooms. Pheromone traps are available for most stored product insects. Provided they are placed in the right distance from each other, far from artificial illumination and draft they are a very useful tool. It should be noted that the numbers of individuals caught by trapping usually allow a good monitoring and may help to find infested products before the problem has spread to other goods in a storage. However, the traps alone are not sufficient for a control of pests.

For products stored in bulk the product temperature may be monitored at different points and in different altitudes as it is done in modern grain storages because raising temperatures are a reliable sign of severe pest infestation. In hard products like grain or pulses hidden insects may also be detected acoustically by the use of especially designed microphones and amplifiers.

Pest control

Disinfestation treatments of stored products often involve the use of fumigants as phosphine or methyl bromide because these gases are fast in action, can be applied without moving the commodity, and are internationally accepted for quarantine treatments. However, the number of available agents is small. During a meeting of the United Nations in 1995 the industrialized countries agreed to fade out the production and use of methyl bromide due to the ozone depleting potential of this chemical. Phosphine (PH_3) is a fumigant used world-wide for disinfestation of a large variety of stored products. Recent research activities concentrate on a more rapid distribution of the fumigant and improved dosage schedules. Wrongly applied, contact insecticides may leave residues in the product unacceptable for the consumer, and in the past several substances lost their efficacy due to the development of resistant insect strains. Other available methods involve the use of controlled atmospheres (CAs), carbon dioxide under high pressure, the use of inert dusts like diatomaceous earth or extreme temperatures. Under certain conditions biological antagonists like parasitoids, predators or entomopathogenic microorganisms may be another means for stored product pest control. First results of a survey using the egg parasitoid *Trichogramma evanescens* as a biological control agent against stored product moths in whole food stores and a whole food bakery are quite promising (see Prozell and Schoeller 1997, this issue).

CA treatments are authorized in several countries for the disinfestation of grain and other dry plant products like nuts, herbs or dried fruits. These goods can be treated either with hypoxic or hypercarbic atmospheres and in the latter case CO_2 contents be may up to 100 %.

Treatments with CO_2 under high pressure of up to 40 bar have to be carried out in pressure proof steel chambers and depending on commodity, pest, temperature, and pressure the treatment times may range from several days to less than one hour. The time of pressure decay at the end of a treatment is another important factor for insect mortality.

Heat and cold treatments do not involve the introduction of any agent and hence do not require registration according to law in Germany. In laboratory studies it was found that temperatures of 55°C kill all stored product pests within a few minutes. Thus, where drying facilities are available they may be used for disinfestation purposes, as well. Heat could also be used for empty room disinfestation of suitable storages and industrial production sites. Conveyor systems cooled with liquid nitrogen or liquid air down to -30°C are offered commercially and allow a disinfestation within minutes. Bagged goods may be treated for some hours in a cooling chamber. The exact treatment times depend on the physical properties of each commodity. This technique is quite costly but short treatment times and the avoidance of any residues may be the most important advantages under certain conditions.

Can we learn from traditional stored product protection techniques?

Most traditional storage and pest control techniques are the result of an evolutionary process. These methods were selected because they proved to be effective under the given conditions. They used available equipment and may be regarded as environmentally safe in most cases. Techniques, such as hermetic storage, the admixture of inert dusts or plant ingredients were used for many centuries. The use of controlled atmospheres as well as diatomaceous earth and the identification of some phytochemicals with insecticidal or repellent properties may be seen as methods derived from traditional techniques. In many cases modern technology allows the identification of the active components or the identification of the basic principles. Some traditional methods like the use of smoke or ashes were discovered to cause health hazards to the user or consumer. But it seems important to document all traditional storage techniques known today in order to assess their efficacy, feasibility and applicability.

CONCLUSION

In conclusion, integrated stored product protection consists of an array of pest prevention, pest detection and pest control methods that need to be implemented and optimized according to each product, pest and storage situation. In order to reduce the application of pest control agents, the future may depend more heavily on pest prevention and monitoring techniques. The relative importance of physical methods like the application of heat or cold, of biological methods like the introduction of predators or parasitoids or the use of residue-free fumigants like nitrogen and carbon dioxide may increase. Customer demands and competition are leading to a documentation of storage conditions and pest control activities for each stored lot. This documentation could also help to reduce time of storage, handling, and ways from producer to consumer. Integrated stored product protection integrates techniques quite different from those in other fields of integrated plant protection. Nevertheless, there is a lot to be integrated out there!

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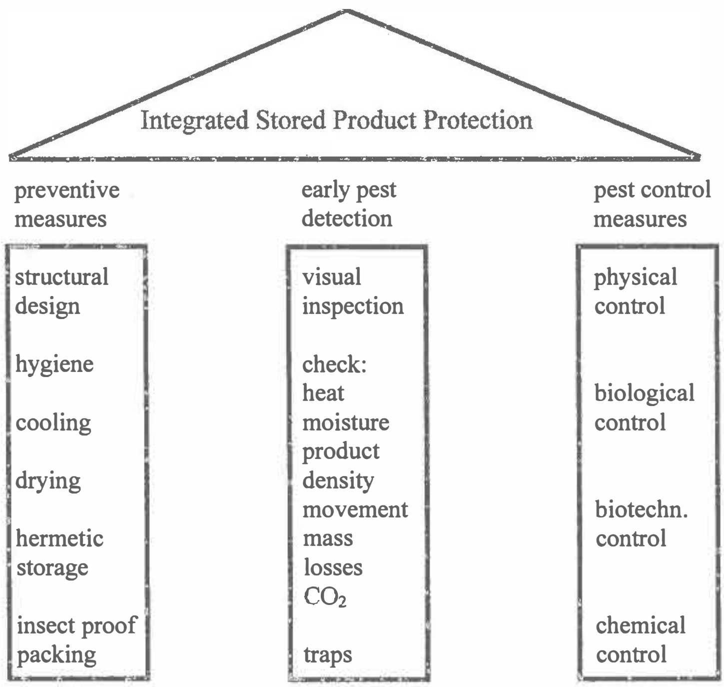

Figure 1 The three columns of integrated stored product protection

Table 1 Influence of product moisture contents on the development of pest organisms in grain

M.C. in grain (%)	**Resulting R.H. (%)** at 20°C	**Potential pest organisms**
< 9	< 30	-
9 - 14	30 - 65	beetles, moths
>14	> 65	beetles, moths + book lice, flies and other insects + mites + microorganisms

Table 2 Response of stored product insects to temperature*

Zone	**°C**	**Effect**
Lethal	50 - 60	death in minutes
	45	death in hours
Suboptimum	35	development stops
Optimum	25 - 33	max. rate of development
Suboptimum	13 - 25	development slows
	8-13	development stops
Lethal	6	death in days (unacclimated), movement stops
	-10 - 5	death in weeks to months (acclimated)
	-18	most stored product insects die
	-25 - -15	death in minutes, insects freeze

*modified from Fields (1992)

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Integrated stored product protection as a puzzle of mutually compatible elements

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ABSTRACT

The concept for integrated stored product protection under evaluation by the ETH and cooperating institutions is presented here.
Different needs and opportunities in stored product protection demand different control techniques. The needs on the farmer's level in tropical countries seem to be particularly promising since they call for non-toxicant means of control allowing safe handling and leaving no or minimal residues only. This paper develops the concept that a combination of biological control and the use of partially herbivore resistant strains of stored goods is a promising approach to meet the mentioned needs.
Three steps must be taken to build up such an integrated system. These may be symbolized by a puzzle consisting of several elements which complement each other:
The first step is to investigate each important element of the puzzle by assessing its size and contour, i.e. its relative significance and its constraints. This is exemplified by the oviposition behaviour of *Callosobruchus chinensis* females on pristine and infested beans.
The second step is to assess the mutual compatibility of the elements by investigating which elements fit together, and which combinations offer added benefits. This is exemplified by the combination of partially resistant beans with biological control. This second step will bring together the core elements of the puzzle. This should be based completely on scientifically sound data.
The third step is to encourage farmers to complement the puzzle with locally adapted means. This is exemplified by integrating solar heating of the stored goods between harvest and storage in order to reduce the initial infestation pressure.

INTRODUCTION

Different needs and opportunities in stored product protection call for different control techniques.

The basic market segmentation distinguishes the following three levels: Bulk storage by government and industry (hundreds of tons), on-farm storage by individual farmers (hundreds of kilograms), and storage for consumption in households (hundreds of grams). The first level often imposes the so-called 'zero-tolerance' for insects, to allow for exportation. The third level may involve the use of mechanical barriers for insects. The principal focus of our projects is on the farmer's level in tropical countries where there is both a need and an opportunity for novel technologies in stored product protection. The farmers in developing countries store their legumes for their family's consumption, but fear of storage pests induces most of them to sell the bulk of their crop produced for marketing immediately after harvest. This leads to severe economic damage: The strongly increased supply during harvest season depresses prices to levels of 50% - 60% below the prices that farmers would be able to obtain if they could safely store their crops for a period of 1-4 months (Schoonhoven, 1976). Pest management is thus either non-existent or relies unilaterally on synthetic insecticides (fumigants and contact insecticides). For both insecticide types user safety, particularly for on-farm use in developing countries, is a critical issue. As for residual insecticides, concern regarding consumer safety is justified, particularly with stored legume grains in which residues must be minimal or completely absent especially with regards to legumes which are consumed raw as sprouts without any previous cooking.

The needs for non-toxic means of stored product protection led to the development of a juvenile hormone type insect growth regulator for safe long-term storage (Dorn *et al.*, 1981) which, however, has not yet been introduced for this use due to high registration requirements including import tolerances, and low expected commercial profits.

An integrated biological approach to stored product pest management on-farm level seems to be particularly promising. Reliable efficacy and mutual compatibility of the elements should be the basis for the farmer's acceptance and subsequent leading involvement.

Step 1: Investigating each important element

Although many potentially important elements of integrated pest management in stored products have been identified so far, precise knowledge of their characteristics is often lacking. A recent review article on stored beans in Africa stated that bean bruchids (Coleoptera: Bruchidae) cause heavy losses in both quality and quantity, but that little or no information is available on their biological control, natural or otherwise, in that continent (Abate & Ampofono, 1996). Furthermore, the use of botanicals as modifiers of herbivore behaviour could be of interest in integrated systems with stored products.

With the ultimate goal of finding useful elements for the protection of stored legume grains, we investigated the oviposition behaviour of *Callosobruchus chinensis* (Coleoptera: Bruchidae) on pristine and infested cowpea seeds, *Vigna unguiculata* (Ignacimuthu, Wäckers & Dorn, in prep.). The female beetles avoided seeds which were infested by feeding larvae, on the long range as well as on the short range, and preferred pristine seeds for oviposition. This capability of the females to orientate their movement by means of olfactory cues and to choose the site for oviposition using chemical substances as major stimuli renders the use of botanical repellents as an element for bruchid management promising.

Knowledge on the size and the contours of each element of the puzzle, i.e. relative significance as well as its contributions and constraints, is a basis for its integration into a more comprehensive protection system.

Step 2: Assessing the mutual compatibility of the elements

Ecologically sound methods are not necessarily mutually compatible. A harmonious combination of several tactics is, on the other hand, a highly desirable strategy for efficacious, reliable and long-term solutions. We must thus first guess which combinations of tactics are likely to meet the needs for on-farm protection of stored legume grain in developing countries, and then try to prove their mutual compatibility.

A combination of optimized biological control and legume cultivars with partial resistance to bruchid beetles is a promising approach. The two methods are expected to complement each other. Furthermore, such a combination has the added benefits (1) that biological control could reduce the risk that a bruchid strain could break the defense mechanisms of partially resistant cultivars, and (2) that the biological control could work faster since the parasitoids have to deal with an overall reduced bruchid density thanks to the partially resistant cultivar.

A number of mutually compatible techniques will finally form the core elements of the puzzle. These core elements must cover the main problems, in our example the key bruchid pests in stored legume grains. Knowledge on the core elements must be based on scientifically sound data.

Step 3: Encouraging farmers to complement the puzzle

Cooperation between selected farmers and scientists should long be established by the time the core elements of the puzzle have been proven useful in on-farm trials. Thus, the respective knowledge can be developed on a number of pilot farms. Farmers who have received a basic introduction into the core elements of integrated pest management are then likely to add more elements to meet their local needs. Quite a number of traditional methods are in use, but scientific verification on their efficacy is still lacking for many of them (Abate & Ampofono, 1996; Van Albeek, 1996).

Solar heating is a method which could be introduced by the farmers as an additional element of the puzzle. Solar heating of harvested legume grains before storage could reduce the infestation pressure by *Acanthoscelides obtectus*, a bruchid which often attacks the legume pods already in the field (Jarry *et al.*, 1987). Thus, integrated stored product protection can be developed and implemented dynamically, and numerous elements will add up to give a comprehensive puzzle.

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Integration of biological and non-biological methods to control arthropods infesting stored products

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ABSTRACT

The compatibility of biological and non-biological methods to control arthropods infesting stored products has been reviewed. Chemical, physical, biotechnical and microbiological methods are discussed as well as resistant crop varieties, conservation of beneficials, kairomones and the manipulation of beneficials and interactions between different species of beneficials. Promising combinations include beneficials and hygiene, modified atmospheres, modification of the storage environment, *Bacillus thuringiensis*, the combination of certain species of beneficials and some natural insecticides. The monitoring of the pest with pheromone traps can help to determine the time of release of mass-reared beneficials. Simulation models can help to optimise the number of releases and released individuals.

Key words: integrated pest management, stored product protection, biological control, predator, parasitoid

INTRODUCTION

Various aspects of integrated pest management (IPM) and biological control were reviewed for storage systems in the tropics by Haines (1984) and Markham *et al.* (1994), and in general by Burkholder (1981), Arbogast (1984), Brower *et al.* (1996) and Schöller et al. (1997). However, the compatibility of biological and non-biological methods has not yet been reviewed in detail . This paper focuses on methods which are currently applied in, or evaluated for the protection of stored products. The term biological control is used in a strict sense as the use of living macroorganisms (Franz & Krieg, 1982). The use of pathogens is referred to as microbiological control, the application of the toxin of *Bacillus thuringiensis* Berliner and pheromone traps as biotechnical methods. A definition for IPM in stored product protection has been proposed by Reichmuth (1996). For a review of the possible components of IPM in stored product protection see Adler (this volume).

Chemical methods

In most cases, the combination of natural enemies and synthetic chemical pesticides will not be possible. Beneficials were found to be as or more susceptible towards chemical insecticides than their respective hosts or preys (Rawnsley, 1959; Boongeua, 1987). The larger corn borer, *Prostephanus truncatus* (Horn), was found to be more tolerant by the factor 1.3 (LD_{50}) to 1.4 ($LD_{99,9}$) to methyl bromide than its histerid predator, *Teretriosoma nigrescens* Lewis (Detmers, 1992). *T. nigrescens* is as susceptible toward pyrethroids as *P. truncatus*, but much more susceptible to Pirimiphos-methyl (Golob *et al.*, 1990). On the contrary, certain pyrethroids are 2 to 145 times more toxic to *Ephestia kuehniella* Zeller than to its ichneumonid larval parasitoid, *Venturia canescens* (Gravenhorst) (Elliott *et al.*, 1983). Burges (1965) was the first who proposed to release beneficials which are resistant towards insecticides into stored product environments. Zil'bermints *et al.* (1986) studied resistant strains of the braconid ectoparasitoid *Habrobracon hebetor* (Say) in Europe, Baker (1995b), Baker & Throne (1995) and Baker *et al.* (1995) in the U.S.A. Keever *et al.* (1986) were able to proof the efficiency of *H. hebetor* in stores with low residues of malathion (<2.0 ppm). Baker & Weaver (1993) found a malathion-resistant strain of the pteromalid ectoparasitoid *Anisopteromalus calandrae* (Howard). Smith (1994b) proposed to release such strains into grain treated with protectant insecticides. No difference in efficiency between a laboratory-strain and an insecticide-resistant field strain of the anthocorid predator *Xylocoris flavipes* (Reuter) to various species of bruchids was found by Sing *et al.* (1996). Therefore, in this case the insecticide resistance was obviously not linked to other biological characters which could have affected the efficiency of the predator. The predatory mite *Cheyletus eruditus* (Schrank) is more tolerant to certain acaricides than its prey, mites infesting stored products. The predatory mites can be released one week after an insecticide treatment (Zdárková, 1996). There are differences in the resistance between different strains of *C. eruditus* to phosphine. More resistant strains should be applied for biological control (Zdárková, 1997). *Trichogramma* spp. are known to be very susceptible to pesticides (Hassan, 1974). However, Brower (1984) found *Trichogramma spp.* in peanut-warehouses, which were treated with malathion and phosphine. Eggs of *Corcyra cephalonica* Stainton sprayed with malathion (0.1%) were extremely toxic for *Trichogramma confusum* Viggiani and *T. japonicum* Ashmead (Navarajan Paul *et al.*, 1976). Compared to the untreated control, only 20% of adult *T. japonicum* emerged from host eggs treated with DDVP (Dichlorvos), and these surviving adults lived for less than 2 h and were infertile. The LD_{50} of DDVP was 532.5 ppm towards larvae and 21.9 ppm towards pupae.

Some natural insecticides were found to be compatible with *Trichogramma*. Following the application of 2000 ppm neem oil (*Azadirachta indica* A. Juss) and neem seed kernel extracts (concentration 5%) on pupae of *Trichogramma japonicum* and *T. chilonis* Ishii, the number of adults emerging was reduced by approximately 18% and 75%, respectively (Muthukrishnan *et al.*, 1993).) In one case the pest's host plant was treated with neem seed kernel extracts and the parasitism of moth eggs by *T. pretiosum* Riley was not affected (Klemm & Schmutterer, 1993). Alcohol- and hexane extracts of neem seed kernels were toxic towards eggs, larvae and pupae of *Bracon brevicornis* Wesm.. *A. indica* of different origins differed in their toxicity, but these differences showed no correlation with the content of azadirachtin, the main active component of *A. indica* (Srivastava *et al.*, 1997). Similarly, *H. hebetor* is adversely affected by preparations of neem (Srinivasa Babu *et al*., 1993). However, some plants used traditionally to protect stored products seem to have no side-effects on beneficials. The treatment of pupae of *Trichogramma* with leaf extracts from *Ocimum* (Labiatae, Ocimoideae) had no negative effect on the number of emerging adults, parasitism, and longevity of the egg parasitoids (Muthukrishnan *et al.*, 1993).

A chemical method which does not build up residues is the treatment with modified atmospheres. The effect of fumigation with carbon dioxide (CO_2) on the adults and eggs of *X. flavipes* was determined (Press & Flaherty, 1978). The eggs were not affected after a treatment of up to 8 h, the mortality increased with increasing exposure, and after a treatment of 20 h, mortality was 100%. The adults were negatively affected after a treatment of 4 h and after 6 h nearly all adults were dead. As *X. flavipes* would not survive such a fumigation, Press

& Flaherty proposed to quickly reintroduce the predators into a store after a fumigation. The predatory bugs could then prey on pest individuals which were not killed by the fumigation or on pests which reinfest the store after the fumigation. In general, the protection of commodities from reinfestation after a treatment with modified atmospheres by releasing beneficials is a promising combination of biological and chemical control (Schöller et al., 1997). The aim of the application of biological control should be the avoidance of the use of synthetic chemical pesticides. Therefore, the integration of synthetic chemical pesticides and beneficials should focus on cases where biological control or its combination with other non-chemical methods fail to control pests sufficiently.

Physical methods

Hygienic and sanitary measures in storage are a prerequisite to avoid the mass development of a pest species. As natural enemies were shown to be most effective at low pest densities (Smith, 1994a; Zdárková, 1996), the development of proper hygiene programmes is therefore a basis for the application of beneficials.

Depending on the optimum abiotic conditions for the development of beneficials and pests, the environmental conditions could be controlled or altered to promote the beneficials (Haines, 1984). For example, *A. calandrae* develops successfully within a wide range of ambient humidity. Therefore, Smith (1993) proposed the release of this species in combination with a low relative humidity in the store, especially at high ambient temperatures. For the system *E. kuehniella* / *V. canescens*, Ahmad (1936) identified a developmental threshold for *E. kuehniella* between 8°C and 10°C and for *V. canescens* between 12°C and 15°C. At temperatures above 23°C, the population of *V. canescens* increased faster. High temperatures favour the parasitoid in this system, low temperatures the host.

Towards microwaves (2450 MHz) *H. hebetor* is at least twice as tolerant as *E. kuehniella*. The integration of beneficials and microwaves to control the Mediterranean flour moth has been proposed by Habib & Fagundes (1996).

The improvement of packages can prevent or delay the infestation of stored foodstuffs. The release of parasitoids in combination with improved packaging can be a method to prevent the infestation of bagged commodities (Cline *et al.*, 1985; Press & Mullen, 1992) or packaged foodstuffs (Cline *et al.*, 1984; 1986; Cline & Press, 1990; Prozell *et al.*, 1995a; b).

The impact of diatomaceous earth on natural enemies has not been studied under storage conditions, but these dusts were applied to crop foliage to suppress aphelinid parasitoids of whiteflies. Dust seemed to interfere with parasitoid behaviour, reducing foraging and oviposition, increasing grooming, and reducing the lengths of visits on dusty surfaces (Bartlett, 1951).

Biotechnical methods

The toxin of *Bacillus thuringiensis* (Bt) has in most cases no or little side effects on parasitoids. The effect of Bt-infected larvae of *E. kuehniella* on the biology of *V. canescens* was studied by Kurstak (1966). Parasitism was not affected. Moreover, *V. canescens* was shown to be a vector for Bt and therefore enhances the spread of the disease in a moth population. Another parasitoid species which was identified as a vector for Bt is *B. brevicornis*. In this species, Bt had a pathogenic effect on the parasitoid. Temerak (1982), Kurstak (1966) and Burkholder (1981) suggested controlling pest populations by spreading viruses and pathogens with the help of parasitoids.

Hagstrum & Smittle (1978) proposed applying growth regulators or methods to induce diapause to keep pest individuals in a developmental stage susceptible for parasitization.

Pheromone traps are very sensitive monitoring tools. Inundative releases of parasitoids were shown to be most effective at the beginning of an infestation (Smith & Press, 1993; Smith, 1994a). Pheromone traps can therefore help to determine the time of release of mass-reared beneficials. In the case of inundative releases, pheromone traps should attract only large numbers of the pest, not the released beneficials. It has been shown that the combination of adhesive- or funnel traps baited with synthetic (Z,E)-9,12-tetradecadienyl acetate (ZETA) are compatible with the inundative release of *Trichogramma evanescens* Westwood. Female egg parasitoids are released without egg-laying experience, and these females do not respond to ZETA. This has been confirmed in field trials (Schöller & Prozell, 1996). In contrast, *V. canescens* is attracted by certain funnel traps (Prozell & Schöller, 1997). The attraction of beneficials by pheromone traps may be a desired feature in classical biological control programs. Both *P. truncatus* and its predator *T. nigrescens* are attracted by the aggregation pheromone of the pest, 'Trunc-call (1+2)' (Helbig *et al.*, 1992). The dispersal of *T. nigrescens* after its introduction into the afrotropical region has been monitored with the help of traps baited with Trunc-call (Böye *et al.*, 1994).

Microbiological methods

From a biological control viewpoint, there are both positive and negative aspects of host-parasitoid-pathogen-interactions. The negative aspects are pathogen-induced mortality of beneficials due to pathogen-produced toxins, the infection of the beneficial and a lower attractiveness of infected hosts as oviposition sites for the parasitoid. Positive aspects are the increase of the probability of predation ,parasitisms of infected pests, and the propagation of pathogens by beneficials. Nuclear-polyhedroses-viruses are known to infect stored product moths. Hassan & Gröner (1977) found no side effects of such viruses on parasitism and development of *Trichogramma*. On the other hand, negative side effects of granulosis viruses of *E. kuehniella* on the braconid *Phanerotoma flavitestacea* were found, but under an identical experimental set-up, no such effects were found with *V. canescens* (Kaya & Tanada, 1972).

Microsporidians were evaluated for the control of *P. truncatus* (Hennig-Helbig 1995). So far, no information seems to be available on possible side effects on beneficials (Brooks, 1993).

The neogregarine *Mattesia dispora* infected *H. hebetor* (Leibenguth, 1972). Healthy adults of the related species, *Bracon mellitor*, did not transmit the pathogen *Mattesia grandis* on host larvae or their own progeny. Moreover, infected parasitoids did not infect the host larvae, but a low percentage of the parasitoid's progeny was infected (McLaughlin & Adams, 1966). Progeny of *T. evanescens* enclosing from eggs infected with the microsporidium *Nosema pyrausta* were heavily infected and the fertility was severely reduced (Huger, 1984). Similar results were obtained for *T. nubilale* (Sajap & Lewis, 1988).

Three species of fungi which are effective antagonists of *P. truncatus*, *Aspergillus ochraceus*, *Metarhizium anisopliae* and *Beauveria bassiana*, were shown to be also lethal to the predator, *T. nigrescens* (Burde, 1988).

Kairomones and manipulation of beneficials

Foraging predators and parasitoids both perceive volatile compounds and contact chemicals produced by their respective prey or host. Thus the bethylid *Laelius pedatus* uses volatiles emitted by larvae of *Trogoderma variabile* (Ballion) and *T. glabrum* (Herbst) for long-range orientation (Qi & Burkholder, 1990), and the pteromalid *Lariophagus distinguendus* Förster is attracted by volatiles from weevil infested grains (Steidle & Schöller, 1997). Both *H. hebetor* and *V. canescens* perceive a product of the mandibular glands of their hosts, larvae of *Ephestia* and *Plodia*, as a kairomone (Corbet, 1971; Strand *et al.*, 1989). Few studies show an increase of parasitism by the additional application of kairomones to a habitat, and no such case is known from stored-product environments. An increase in parasitism by *Trichogramma* after spraying hexane extracts of host moth scales, which elicit arrestment behaviour in the egg parasitoids, was shown by Gross *et al.* (1984) in cotton. In field crops, kairomones were evaluated for the prevention of dispersal of beneficials away from the site of infestation. In the relatively closed stored product environments, such a dispersal has not been observed so far. Only in the laboratory, did dispersal occur at high population densities (Takahashi, 1973). However, the artificial contamination of a stored product environment with kairomones may lower the efficiency if the beneficials are inundatively released. The beneficials are expected to be attracted or arrested at the site of kairomone application. At the scale of the pest's microhabitat, the pest individuals may be aggregated at another site, and the beneficials would loose foraging time while examining pest-free areas.

Burkholder (1981) suggested attracting parasitoids with food sources or with the aid of their pheromones.

Conservation of beneficials

Populations of beneficials can be conserved by the provision of food, prey or hosts. This may be especially important in times of low host availability (Arbogast 1984). Nickle & Hagstrum (1981) proposed providing paralysed larvae to conserve *H. hebetor*, as the larvae are both food and oviposition substrate for these braconids. In cotton fields, augmented densities and distributions of moth host eggs were used to increase parasitism by *T. pretiosum* (Gross *et al.*, 1984) The provision of honey as food increases the parasitism of *Callosobruchus chinensis* (L.) by *A. calandrae* in cowpea, especially if the parasitoid has got exclusive access to the food, as *C. chinensis* also feeds on honey (Wäckers, 1996; this volume).

Stores of subsistence farmers in tropical regions are mostly open for the invasion and dispersal of both pests and beneficials, and the products may be already infested in the field (Alebeek, 1996). Under such conditions, conservation techniques developed for field crops may be applied, like the provision of food plants or alternative host's food plants near the stores.

Interactions between different species of beneficials

The combined release of predators and parasitoids or parasitoids which attack different developmental stages of the host can improve the efficiency of biological control and help to overcome pest complexes (Keever *et al.*, 1986). This was shown for *V. canescens* and *X. flavipes* (Press, 1989), *T. pretiosum* and *H. hebetor* (Brower & Press, 1990) and *T. nigrescens*, *Theocolax elegans* Westwood and *A. calandrae* (Böye 1988). On the other hand, beneficials may adversely affect each other. In a laboratory set-up, *H. hebetor* suppressed *V. canescens* in a culture of *Cadra cautella* Walker (Press *et al.*, 1977). *T. pretiosum* parasitised eggs of *X. flavipes*. *X. flavipes* preyed on moth eggs parasitised by *T. pretiosum* (Brower & Press, 1988). Hase (1924) found *L. distinguendus* parasitising larvae of *H. hebetor* after they spun their cocoon, and *X. flavipes* was found to prey upon the larvae of *H. hebetor* (Press *et al.*, 1974). *Lyctocoris campestris* (F.) also feeds on larvae and eggs of *H. hebetor* and *L. pedatus* (Parajulee & Phillips, 1994). Hardy & Blackburn (1991) found indirect evidence, that *H. hebetor* destroys eggs of the bethylid *Goniozus nephantidis* Muesebeck. *T. nigrescens* preyed in no-choice-tests on immature stagesof *A. calandrae*, but did not so in a choice situation when immature stages of *P. truncatus* were present simultaneously (Murphy & Cross, 1992).

Further methods

Beside the methods discussed earlier, the use of resistant grain varieties can enhance the effectiveness of biological control. Ofuya & Credland (1995) showed, that the development of larvae of *Bruchidius atrolineatus* (Pic) has been prolonged in certain varieties of cowpea (*Vigna unguiculata* Walp.). The prolonged larval period increases the opportunity for parasitoids like *Eupelmus vuilleti* (Crawford) and *Dinarmus basalis* (Rondani) to parasitise the larvae. Beside the methods of control and prevention, the socio-economic constraints have to be analysed. In tropical countries for example, surveys of the rural storage situation were accompanied by farmer interviews. The results were statistically analysed using multivariable techniques. With this approach, the traditional storage techniques can be preserved and certain management practices can be correlated with insect infestation or its absence (Markham *et al.*, 1994). Interviews with retailers, millers, storekeepers and consumers could also be a way to learn more about the needs and expectations concerning stored product protection in industrialised countries. Especially in IPM-programs, the participation of the forenamed groups is necessary, and training and information is crucial for the acceptance and realisation of biological control.

CONCLUSIONS

Currently, many stored product pest control systems are based primarily on the use of pesticides. Pest management has been improved in some fields through the reduction of the quantity of pesticide used by monitoring. The development of pesticide resistance by key pests, legal restrictions on essential pesticides, consumer attitude and the development of biological control methods might lead to the transformation of such systems. For many possible components of IPM, examples in the literature, where the combination of biological and non-biological control methods is promising, is abundant.. Above all hygiene, modified atmospheres, modification of the storage environment, Bt, the combination of certain species of beneficials and some natural insecticides were identified to have great potential. This may enable biological control to become a component of IPM in stored product protection. The monitoring with pheromone traps can help to determine the time of release of mass-reared beneficials and simulation models can help to optimise the number of releases and released individuals.

On the other hand, there are at least as many examples where integration seems impossible. Even different beneficials may affect each other adversely. The factors which determine the compatibility mostly depend on the species. Therefore, the identification of the pest species and the detailed analysis of the conditions of storage is the basis to applying biological control. However, this may be time consuming and will require well trained pest control personnel. The number of available pesticides applicable to control stored product pests is declining. There are already many regulatory and socio-economic constraints which require a detailed analysis of what is going on in a store. This may favour biological control to become part of an IPM program in stored product protection.

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A Review of the options for biological control against invertebrate pests of stored grain in the UK

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ABSTRACT

Following a review of work in other countries, biocontrol agents with the most immediate potential for use in UK grain stores appear to be a mixture of beneficial insect and mite species, or the insect pathogen, *Bacillus thuringiensis*. Both types of agent could be incorporated into an integrated pest management programme aimed at reducing conventional pesticide usage. However, research on their use under UK commercial conditions is required before any firm recommendations can be made. Beneficial insects and mites have the advantage over microbials of not requiring registration, a process that might be considered prohibitively expensive by potential manufacturers. Representatives of the UK grain industry stated that they would be interested in biocontrol if current control measures became unviable or if biocontrol was shown to be equally effective and less expensive. Millers and food manufacturers were concerned that the addition of biocontrol agents to grain would be condemned as contamination under present food safety regulations. Nevertheless, the industry is under increasing pressure to reduce pesticide usage; the development of new pest management strategies incorporating effective biocontrol agents deserves further consideration.

INTRODUCTION

In the UK around 20 million tons of grain are stored annually in about 50,000 farm grain stores and 500 commercial grain facilities (Anon, 1995a,b,c). Commonly, stored grain has been protected from insect and mite attack by the use of pesticides. For example, 15.8 tons of pesticide active ingredients, over 80% of which were organophosphates, were used in farm grain stores in Great Britain during the 1994/95 storage season (Norris and Garthwaite, 1997). However, the industry is under increasing pressure to reduce pesticide usage because of concerns about safety, stricter legislation on the use of pesticides, and increasing pest resistance. Some pesticide users are worried about operator exposure to pesticides and sectors of the public are concerned about residues in food. At the same time the demand for pest-free grain continues. The use of biological control agents in the UK is one option being considered, following a recent review of their potential by the Central Science Laboratory (CSL) for the Home-Grown Cereals Authority (HGCA) (Cox and Wilkin, 1996). This paper summarizes the main findings from that review and highlights some options for the incorporation of biocontrol agents within an integrated control strategy.

LEGISLATION ON BIOCONTROL AGENTS

(a) Registration

The use of pesticides in the UK is controlled by a number of statutory measures, including the Control of Pesticides Regulations (COPR) 1986. The Pesticides Safety Directorate (PSD) of MAFF is the authority running the pesticide registration scheme, and they charge about £20,000 (SWF 46,000) for each product. In addition, the company submitting the registration must also meet the costs of developing the necessary efficacy and safety data package and, even for a conventional pesticide, this can be several hundred thousand pounds. The registration package must include data on efficacy to show that the product gives a level of control against each pest species that is at least comparable to current products, and that any residues left in the grain do not represent a risk to consumers and do not adversely affect processing, the environment or non-target organisms. Fungi, protozoa, bacteria, viruses and mycoplasmas used for pest control require registration under the COPR whereas insects, mites and nematodes do not. Furthermore, if the insect, mite or nematode was regarded as an endemic species in the UK, supplies intended for use as control agents could be imported without the need for an import license.

(b) Food safety regulations

The food safety regulations have been drawn up primarily to protect the consumer and to ensure that food for human consumption is not injurious to health. A recent tightening of these regulations in the UK has designated all grain stores as food premises and subject to the Food Safety Act (Anon., 1990). Further changes may occur when plans to establish a new Food Standards Agency are implemented. At the moment, however, the situation in the UK regarding the release of beneficial insects into grain is not entirely clear, as the Food Safety Act does not distinguish between beneficial and pest species in food products. Similarly, it is uncertain how EU food regulations might be interpreted. Nevertheless, as far as the presence of insects and mites in finished cereal products for human consumption is concerned, any beneficials carried over from the grain store would need to be removed during the usual cleaning procedures before final processing.

VIEWS OF THE CEREALS INDUSTRY AND END-USERS OF GRAIN

Information was sought from small but representative samples of several sections of the UK grain industry, including individual companies, organizations and some end users of grain, to assess their reactions to the possible use of biocontrol. The storekeepers approached were interested in the use of biological control agents but were concerned about possible adverse reactions from end-users, and whether the cost and efficacy of biocontrol would match current control. Flour millers were opposed to the concept of adding any biological agents to grain intended for milling flour. Identification of pests at the intake points of mills remains a problem and the possible addition of beneficial insects and mites would only compound the problem for millers. Microbial agents would also be unacceptable at present because of public concerns over health and safety. The Guild of Conservation Grade Cereal Producers indicated that their members would be interested in adopting biocontrol methods for grain pests. End-users of Conservation Grade cereals, however, were more cautious, particularly because some of their products incorporate cereal grains in a relatively unprocessed form. Clearly, any insect contamination, regardless of status, is unacceptable in such products.

In spite of general satisfaction within the UK cereals industry with current pest control methods, the industry is aware of continued public concern over control strategies that rely heavily on chemical pesticides especially where food is concerned. It is highly likely that, given a choice, the consumer would prefer food to be free from all pesticide residues providing this did not lead to lower standards of food hygiene, the presence of beneficial insects in food or much higher prices.

VIEWS OF COMMERCIAL SUPPLIERS OF BIOCONTROL AGENTS

Companies operating in the UK and currently providing biocontrol products for the horticultural trade saw stored products as a potential new market. Although not producing predators and parasitoids to control grain pests at present, they would be eager to respond as soon as a demand for such products was perceived. They considered that demand was most likely to be stimulated by pressure from maltsters and large food retailers for pesticide-free grain, rather than the cereals industry itself. Stricter legislation restricting pesticide residues in food, and other environmental issues, would provide further encouragement. The biocontrol companies were confident they could adapt existing production units and release systems for grain pest biocontrol agents. However, before committing the necessary resources they would need to be convinced of the efficacy of any potential agent, and that the market was sufficiently large and secure to justify the start-up costs involved. As far as microbials were concerned, there were several promising candidates awaiting development but the size and potential return from the market in the UK did not appear to justify the costs of registration at present.

CURRENT RESEARCH AND STRATEGIES FOR USE IN THE UK

There is comparatively little work specifically concerned with the biocontrol of stored product pests in progress in the UK. However, CSL has an interest in several areas of biocontrol, and holds stocks of some key predators and parasitoids of grain pests for use in some preliminary studies. There are limited programmes in a few universities but these are concerned mainly with laboratory population dynamics and modeling of predator/prey relationships. A review of the literature together with information obtained from some key research workers in the USA, Europe and Asia, highlighted the strengths and weaknesses of the main groups of biocontrol agents. In the short term, four control strategies were judged to have some potential for use in the UK:

(a) Predators and parasitoids

Several companies in the USA supply beneficial insects and mites for release throughout the storage period on a weekly basis according to the level of pests present. Published information on costs vary from £0.5 to £1.2 (SWF1.2-2.8) per ton of grain for this system. This compares with figures ranging from £0.4 to £1.2 (SWF0.9-2.6) per ton for conventional insecticides applied as dusts or sprays. However, recent laboratory studies in the USA suggested that multiple releases of the parasitoid, *Anisopteromalus calandrae* were no more effective in suppressing populations of the maize weevil, *Sitophilus zeamais*, than was a single, less expensive release of the same number of parasitoids (Wen and Brower, In prep). Some of these biocontrol agents may be suitable for use under UK storage conditions. CSL is currently investigating the potential of some parasitoids to control beetle pests, possibly by introducing them into empty grain stores to eliminate residual populations of pests before freshly harvested grain arrives. These parasitoids occur naturally in the UK and so their registration as biocontrol agents would not be necessary.

(b) Predatory mites

The predatory mite, *Cheyletus eruditus*, is used in the Czech Republic to control grain mites. They are applied at the rate of about 2000 mites per $100m^2$ of floor area in an empty store (Zdárková and Horak, 1990). When treating grain, the predators must be applied early in the storage season to the grain surface to give a predator : prey ratio of at least 1 : 100, rising to 1 : 10 for heavy pest populations or at temperatures below 18°C where this predator is not so effective. Costs to treat empty stores or grain under average storage conditions are about £2 (SWF4.6) per $100m^2$ of surface area. This strategy would appear to have potential for mite control in stored oilseeds in the UK where mites resistant to conventional pesticides are a growing problem (Prickett, pers. comm.). This predator is widespread in the UK and so registration would not be necessary.

(c) Microbials

The storage moth control product "Dipel", containing the insect pathogen *Bacillus thuringiensis,* is registered in the US for application to the surface of grain. Current USA prices suggest the costs of "Dipel" would be about £0.3 (SWF0.5) per m^2 of grain surface. At present, this system could not be used in the UK because "Dipel" or equivalent products and other strains of *B. thuringiensis* with the ability to control beetles would first require registration by PSD.

(d) Integrated Pest Management

Further progress in the use of biocontrol for stored grain may come through integrated pest management (IPM) strategies. IPM combines different types of control methods to minimize the use of chemical pesticides without lowering the market value of the product due to pest damage. Reviewing the use of IPM for stored product insects, Subramanyam and Hagstrum (1995) and Schöller *et al.* (1997) concluded that, although IPM is more complex and requires greater effort than other control strategies, it should lead to more reliable pest management decisions. A new version of an IPM strategy for UK grain storage has been developed by CSL and Imperial College. Non-chemical methods such as cooling and drying form the basis of the strategy, and the results of new research at CSL are brought together in a computer-based decision support system, called the Integrated Grain Storage Manager. CSL could replace some of the conventional pesticides with biocontrol agents in this system.

CONCLUSIONS AND RECOMMENDATIONS

Despite the lack of enthusiasm in the industry for the introduction of biocontrol at the moment, its further development is important from a strategic standpoint. For example, a number of current pesticides are unlikely to be supported by their manufacturers during the European re-registration process. There is little if any sign of new chemical methods being developed. Therefore, at some point in the future, biocontrol could become one of the only options to control pests in some circumstances. It can also be regarded as a potentially important element in IPM programmes for stored grain.

Additionally, the increased demand for organic grain might stimulate more interest from the cereals industry. For example, at present only about 15,000 tons of “organic” wheat is grown annually in the UK. Demand from both millers and animal feed compounders far exceeds this small production and is forecast to continue to rise (Long, 1997). However, even in the “organic” grain sector much will depend upon a clarification of the status of biocontrol agents added to stored grain in relation to UK and EU food regulations.

There is a large body of data from laboratory studies and, to a lesser extent, from field trials to show that all pests of stored grain are susceptible to a range of biological agents. However, a critical look at their potential suggests that only a small number of biocontrol strategies have any likelihood of commercial viability in the UK in the immediate future. The most promising strategies for research would appear to be using a mixture of beneficial insects to disinfest empty stores prior to the arrival of fresh grain, and using predatory mites in grain or oilseeds. The next steps for developing biocontrol strategies for UK grain stores are the production of relevant efficacy and cost data, concentrating on the few biocontrol agents that have been shown to work in other countries and for which a commercial supplier would be available. Continued liaison with workers throughout the world and particularly in Europe is vital if biocontrol in this field is to progress further.

A key feature in future progress will be the attitudes of governments and official bodies towards funding of such work, since it is unlikely that companies supplying biocontrol agents will be able to support this type of development work. Practical trials are essential to test the value of various biocontrol agents under commercial storage conditions and their acceptability to end users. Such trials will also be of fundamental importance in influencing the attitudes of both storers and end users of grain in favor of adopting the new methods.

ACKNOWLEDGEMENTS

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No endorsement of named products is intended nor is any criticism implied of other alternative but unnamed products.

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Classical Biological Control

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Prospects for developing strategies for biological control of the mediterranean flour moth *Ephestia kuehniella* in flour mills

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ABSTRACT

The most important pest in Danish flour mills is the Mediterranean flour moth *Ephestia kuehniella* Zeller (Lepidoptera: Pyralidae). With the phase out of methyl bromide in Denmark in 1998, new strategies must be applied to control insect pests in mills. A five-year project has recently started at the Danish Pest Infestation Laboratory, the aim of which is to develop strategies for biological control of *E. kuehniella*. The project includes the development of a simulation model for the evaluation of candidate control agents as well as of different strategies for introducing the natural enemies in the mills. A 12- month monitoring programme has been initiated in which temperature and humidity as well as densities of pests and natural enemies will be registered in two industrial mills. Two species of natural enemies have been selected for further investigation; a special strain of the parasitoid *Trichogramma evanescens* Westwood (Hym.: Trichogrammatidae) and the predatory mite *Blattisocius tarsalis* (Berlese) (Acari: Ascidae).

Key words: *Ephestia kuehniella*, Mediterranean flour moth, flour mills, pheromone trap catches, simulation model, biological control, predators, parasitoids, *Trichogramma evanescens*, *Blattisocius tarsalis*.

INTRODUCTION

Flour production in industrial mills can be disturbed by the presence of a number of insect and mite pests. In Scandinavia the most common pest is the Mediterranean flour moth *Ephestia kuehniella* Zeller (Lepidoptera: Pyralidae). For many years control of *E. kuehniella* in mills has been carried out by means of methyl bromide fumigations once or twice a year. Methyl bromide is considered to contribute to a depletion of ozone in the upper atmosphere and use of this fumigant is to be phased out in industrial countries within the coming years. In Denmark it has been decided that use of methyl bromide is to cease as per December 31, 1997. Although *E. kuehniella* can be controlled by a number of pesticides, no method exists that can completely replace methyl bromide in mills (UNEP, 1995; Hansen & Mourier, 1995).

In the future, pest control in mills will have to be based on integrated pest management (IPM), i.e. a combination of prevention, improved hygiene and use of other control methods such as spot treatments with liquid pesticides and alternative methods e.g. application of inert dusts. It has been shown that a formulation of diatomaceous earth can prevent the development of *Ephestia kuehniella* (Hansen & Nielsen, 1996; Nielsen, 1997a). In Denmark, however, diatomaceous earth products are unlikely to be registered due to concern of adverse affects on humans.

Conditions in mills are considered to be ideal for successful biological control: they have relatively stable climatic conditions, a continuous presence of resources (grain particles, flour) for the pests in crevices and structural voids as well as relatively free access between different regions/areas in the mill. Despite early reports on suppression of *Ephestia kuehniella* in flour mills by natural enemies (Buchwald & Berliner, 1910; Geickie, 1887; both referred to by Brower *et al.*, 1995; Schöller, *et al.*, 1997)), very little emphasis has been placed on development of biological control in mills. Helbig (1996) suggests that the use of biological control against post-harvest insects has an intermediate potential in processing industries, which includes mills.

At the Danish Pest Infestation Laboratory a five-year project was initiated in 1996, the purpose of which is to develop biological methods for the control of *Ephestia kuehniella.* The project focuses specifically on the effect of predators and parasites on populations of *E. kuehniella*. Below, the project elements and preliminary results from the first year of the project will be presented.

Project elements

1. Development of a simulation model

The first phase of the project has been aimed at developing a distributed-delay simulation model of *E. kuehniella* populations in mills. The model is intended as a low cost tool for evaluating which major factors govern the population dynamics of *E. kuehniella* and selected natural enemies. Furthermore, the model will be used for evaluating different control strategies in an integrated control context. The model is based on one that has been developed to describe population development of the larger grain borer *Prostephanus truncatus* (Meikle *et al.* 1997).

Developmental and mortality parameters for eggs, larvae and pupae, life span and fecundity of adult insects have been estimated from published data and entered into the model (H. Skovgaard & N. Holst, pers. comm.). The overall phenology of moth dynamics is reflected in pheromone trap catches, which will be used to validate the model.

Temperature is important for the developmental rate and survival of the pest. However, as no information is available on the climatic conditions inside a mill, outdoor temperatures have been used in the model. In this case the model underestimates the population densities late in the season, probably because temperatures in the mills are generally higher during the autumn months due to heat development from machinery.

The model has facilities for entering the biological data of a selected natural enemy to assess its effect on the flour moth population development.

2. Monitoring programme

A 12-month monitoring programme has been initiated in February 1997 in two industrial flour mills. Temperature and humidity conditions, both internally as well as externally, will be registered in order to obtain further input for the simulation model. The activity of the flour moth and naturally occurring parasitoids or predators are being monitored by means of pheromone traps, sticky traps and UV-sterilized flour moth eggs in these two mills, as well.

Temperatures registered during the first 6 months of the monitoring programme are shown in fig. 1. In each mill, mean daily values from the areas with the highest and lowest temperatures, as well as the recordings of the ambient (outdoor) temperatures are shown. In general, temperatures inside the mill follow the development of the outdoor temperatures, reaching unusually high levels due to record heat in Denmark in August. Some areas of the mill have relatively high temperatures, e.g. the screenroom of mill R, where the mean daily temperatures varied between 12° and 35°C. The area with the lowest temperatures, the silo inlet area in mill V, shows variations between 5° and 27°C. These data will subsequently be used to regulate the simulation model.

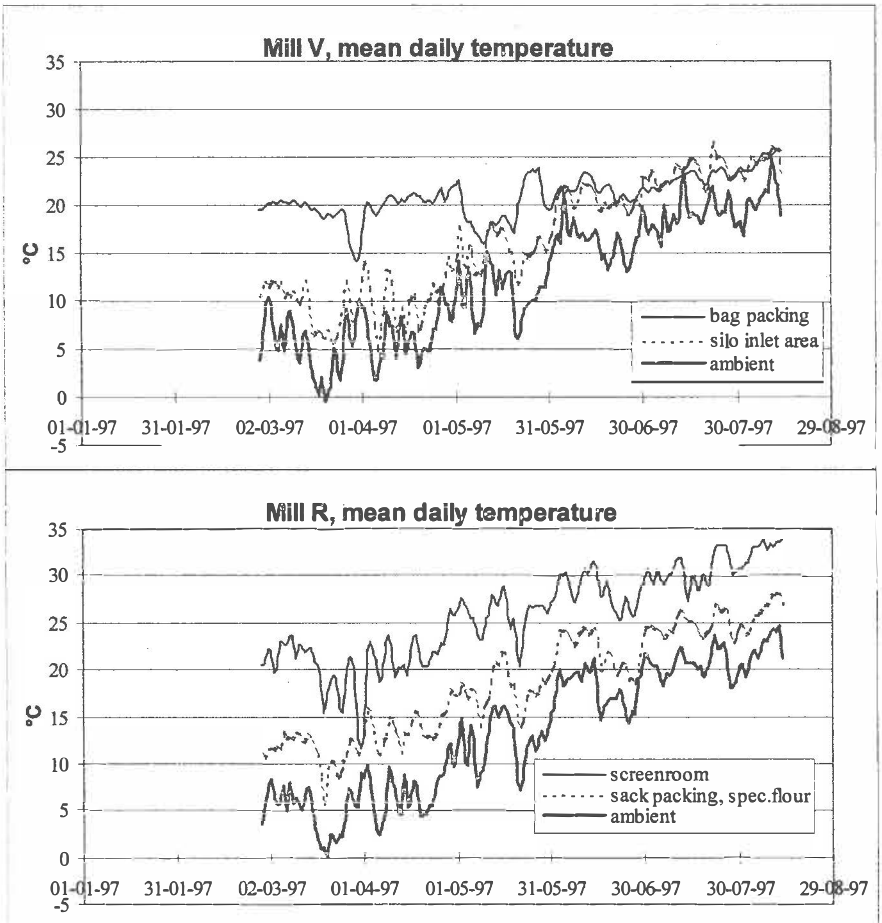

Fig. 1 Examples of temperature recordings from the two mills. In each mill the area with the highest and lowest temperatures are shown as well as the outdoor (ambient) temperatures. Daily mean of recordings every 6 hours.

Flour moths were present in both mills when the monitoring programme started in February. In one mill the moth population in some areas quickly reached a level that necessitated control measures. Pheromone trap data from selected areas in the mills will be presented.

In one mill, a few specimens of parasitic wasps (Mymaridae) as well as activity of an unidentified predator have been recorded (results from February until mid-August).

3. Laboratory investigations

Investigations are being carried out in the laboratory to elucidate the effect of temperature on pheromone trap efficiency. This is necessary before trap catch data from the mills can be used for validation of the simulation model.

The investigations will include observation of moth activity as well as the proportion of flour moths that are recorded in pheromone traps at temperatures from 5° to 35°C (C. Nansen, pers. comm.). Preliminary results of the investigations will be presented.

4. Selection of relevant natural enemies

At present, two species have been selected for further investigation:

- a strain of *Trichogramma evanescens* Westwood (Hym.: Trichogrammatidae), that had been collected in stored grain. This species was chosen due to previous studies at Institut für Vorratsschutz, BBA, Berlin (Schöller *et al.* 1994) and scientific contacts with S.A. Hassan, BBA, Darmstadt.

- a predatory mite, *Blattisocius tarsalis* (Berlese) (Acari: Ascidae). This species had proven to be a promising candidate in preliminary studies at the Danish Pest Infestation Laboratory (Nielsen, 1997b).

Both species have been established in the laboratory and investigations of relevant aspects of their biology have been initiated. Details for the plans for *Blattisocius tarsalis* can be found later in these proceedings (Nielsen, 1977b).

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Insect fauna of a bakery, processing organic grain and applying *Trichogramma evanescens* Westwood

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ABSTRACT

The insect fauna of an industrial bakery processing organically produced grain was surveyed for four years. The most important pests monitored inside and outside the bakery with ZETA-baited pheromone traps were *Ephestia kuehniella* and *Plodia interpunctella* (Lepidoptera: Pyralidae). In the second year, *Trichogramma evanescens* (Hymenoptera: Trichogrammatidae) was mass-released. Compared to the year before the introduction of *T. evanescens*, the number of moths trapped in the following three years was reduced by 80%.
Simultaneously with *T. evanescens* the following parasitic Hymenoptera were found: *Venturia canescens* (Ichneumonidae), *Habrobracon hebetor* (Braconidae) and *Holepyris sylvanidis* (Bethylidae). The parasitoid of *Tribolium confusum* (Coleoptera: Tenebrionidae), *H. sylvanidis*, was recorded for the first time in Berlin/Brandenburg.

Key words: parasitoid, stored product protection, biological control, food processing industry

INTRODUCTION

As a rule, the fauna of stored products of plant origin consists of a complex of pests and beneficial insects belonging mainly to Coleoptera, Lepidoptera, Hymenoptera. The use of parasitoids in order to regulate the density of those insects infesting stored products is one possible component in an integrated stored product protection program (SCHÖLLER et al. 1997). In the stores of retail trade egg-parasitoids of the genus *Trichogramma evanescens* WESTWOOD have been used against several species of pyralids infesting stored products (BROWER 1990, PROZELL et al. 1995, SCHÖLLER et al. 1995). *Trichogramma* mainly parasitises Lepidoptera. The host specificity of such parasitoids may be a disadvantage, if a complex of pests has to be controlled. Therefore, besides retarding the development of pyralid populations the abundance of other pests is crucial to the economic success or the failure of the use of parasitoids.

MATERIAL AND METHODS

The food processing plant, an industrial bakery, uses exclusively organically produced grain. According to the regulations of the organic trade no synthetic, chemical insecticides are applied. The insect fauna was surveyed from September 1st 1994 till March 15th 1997. The pyralid population was monitored by pheromone-traps which were baited with (Z,E)-9,12-tetradecadienyl-acetate (ZETA). ZETA is the main component of the female sexual pheromone of Plodia *interpunctella* (Hübner) and *Ephestia kuehniella* Zeller (KUWAHARA et al. 1971). 16 delta-traps, fitted with Mottlock®-Maxi sticky bottoms in which ZETA was included into the glue were used from 1995 - 1996. In areas where a large amount of flour was processed, 4 funnel-traps were also set up. 4 delta-traps were placed outdoors in the immediate vicinity of the industrial bakery. To the west of the monitored bakery there was a conventional bakery and in the east a garage. Between each of the buildings two traps were placed (Figure 1 and 2). The delta-traps were checked at three-months intervals and the funnel-traps weekly.

To determine the presence of naturally occurring larval parasitoids of pyralids, they were lured with the aid of larvae of *E. kuehniella*. Larvae of different developmental stages were introduced into wire mesh cages (mesh size 1,5 mm), measuring 7,8 cm in length and 1,4 cm in diameter and placed inside the bakery. After a exposure time of one week, larvae were brought to the laboratory and checked for parasitism.

Furthermore, four common Tribolium-traps, AgriSense WindowTrap®, were used for about one year. After this period the traps were supplemented with wheatgerm oil as an additional bait. The traps were changed every three months. Other insect species were caught manually.

Since July 1995 *T. evanescens* were released from 55 releasing sites. The release-unit was a cardboard-card (Tricho-card), each containing an estimated 2000 parasitised *Sitotroga cerealella* (Olivier) eggs. Each egg card comprised a variety of different developmental stages. Thus, a continuous emergence of adult wasps was guaranteed over a period of two weeks, before the egg-cards were replaced. The eggs of *S. cerealella* had been sterilized by the use of an OSRAM HNS 30W OFR light for one hour - before the parasitisation in order to avoid the hatching of *S. cerealella* moths from unparisitized eggs. The adult emergence of *T. evanescens* from the Tricho-card was checked every week.

RESULTS

The insect species found in the bakery are listed in Table 1. *P. interpunctella* and *E. kuehniella* were caught by pheromone traps. *Pyralis farinalis* L. was not found in the traps, but was caught manually. The total number of *P. interpunctella* and *E. kuehniella* caught in pheromone traps inside the factory (from September 1994 - July 1995) before the release of *T. evanescens,* was on average 250 per month. After the release of *T. evanescens*, from July 1995 to June 1997, the number of moths caught was reduced by 80% to an average of 50 moths per month. *P. interpunctella* was not trapped from January 12th till February 16th 1996. Otherwise, both insects occurred during 1996 - 1997.

Outside the factory *P. interpunctella* and *E. kuehniella* were trapped from April to October 1996 (Figure 1) and April to August 1997 (Figure 2) in the pheromone traps. The traps between the monitored bakery and the neighboring conventional bakery caught about five times as many pyralids as those between the monitored bakery and the garage. More *E. kuehniella* were caught outdoors than inside the bakery. In 1997, the number of moths caught outside was 10 fold than 1996.

Holepyris sylvanidis and *Venturia canescens* were also caught regularly in the funnel traps. From these wasp catches it can be hypothesized that both species do not enter diapause under the conditions studied, which confirms the previous observations made by Beling (1932).

Tab. 1: List of insect species found in an industrial bakery which processes organically grown grain and uses *Trichogramma evanescens*.

Species		Family	Order	Status
Lepisma saccharina L., 1758		Lepismatidae	Zygentoma	synanthrop
Tribolium confusum JACQUELIN DU VAL, 1868		Tenebrionidae	Coleoptera	stored product pest
Tenebrio molitor (L., 1758)	*	Tenebrionidae		stored product pest
Oryzaephilus surinamensis (L., 1758)		Silvanidae		stored product pest
Ernobius mollis (L., 1758)	*	Anobiidae		synanthrop
Sitophilus granarius (L., 1758)		Curculionidae		stored product pest
Venturia canescens (GRAVENHORST, 1829)		Ichneumonidae	Hymenoptera	beneficial insect
Habrobracon hebetor (SAY, 1836)		Braconidae		beneficial insect
Holepyris sylvanidis (BRETHES, 1913)		Bethylidae		beneficial insect
Nemapogon granellus (L., 1758)	*	Tineidae	Lepidoptera	stored product pest
Pyralis farinalis (L., 1758)	*	Pyralidae		stored product pest
Ephestia kuehniella ZELLER, 1879		Pyralidae		stored product pest
Plodia interpunctella (HÜBNER, 1811)		Pyralidae		stored product pest
Drosophila funebris (F., 1778)		Drosophilidae	Diptera	synanthrop
Calliphora vicina (ROBINEAU-DESVOIDY, 1830)	*	Calliphoridae		synanthrop

* only one specimen found

From September 1st, 1994 till June 1st, 1996 *Tribolium confusum* was not caught by the common *Tribolium* traps, after the traps were supplemented with wheatgerm oil as bait, *T. confusum* was caught regularly over the rest of the period.

Besides the insects listed in Table 1, different species of Thysanoptera, Heteroptera, Homoptera, as well as spiders were found.

DISCUSSION

The absence of *P. interpunctella* in Winter 1996 was probably due to larval diapause or low population densities that could not be monitored by the trap. The outdoor catches showed the migration of pyralids between the two industrial bakeries. For Autumn 1996 the direction of movement of *E. kuehniella* can be derived from the outdoor catches and the catches made inside the organically producing bakery. The origin of the Mediterranean flour moths caught in the outdoor traps was most likely the conventional bakery, as the traps near the door of this bakery caught the highest numbers of moths.

Other pests mentioned in Table 1 occurred, before as well as after the use of *T. evanescens,* in low, economically unimportant densities or could be recorded only once.

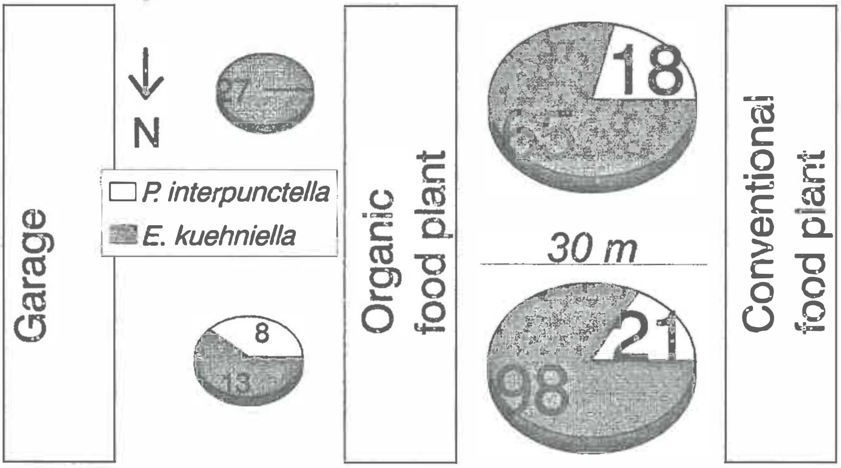

Figure 1: Total number of pyralids trapped with pheromone traps in the vicinity of an industrial bakery processing organically grown grain and using beneficial insects (B), and an conventional industrial bakery (K). Number of catches from April to August 1996.

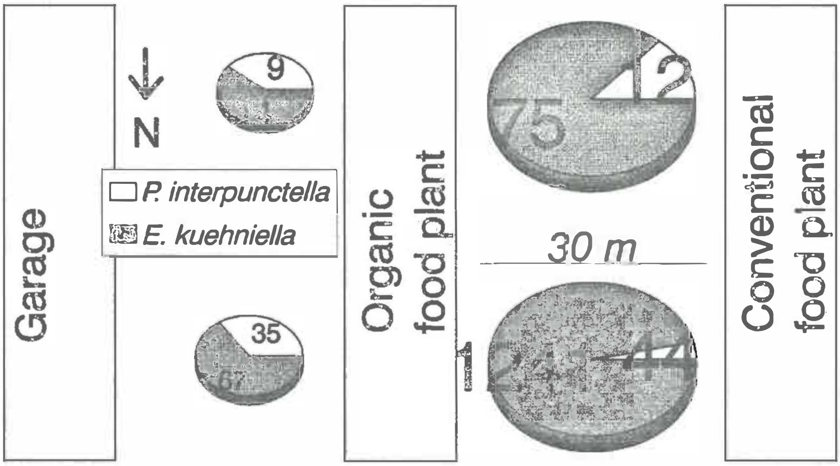

Figure 2: Total number of pyralids trapped with pheromone traps in the vicinity of an industrial bakery processing organically grown grain and using beneficial insects (B), and an conventional industrial bakery (K). Number of catches from April to August 1997.

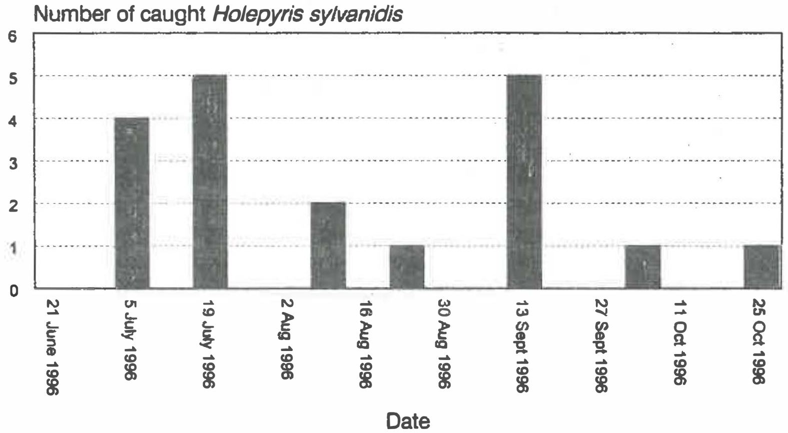

Figure 3: Number of *Holepyris sylvanidis* trapped with ZETA-pheromone funnel traps inside an industrial bakery processing organically grown grain

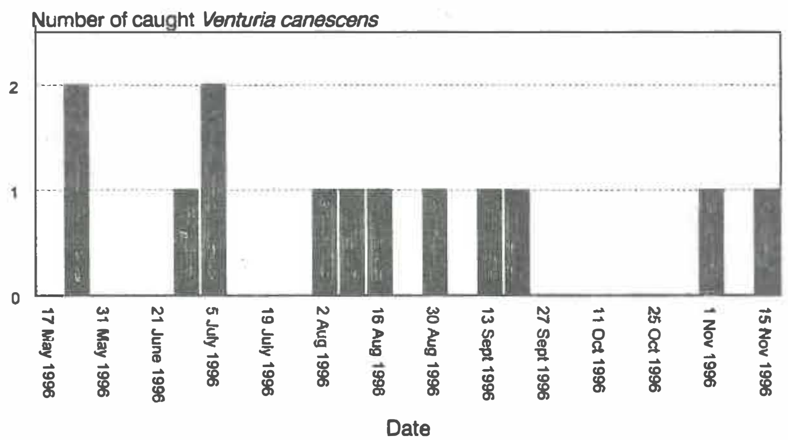

Figure 4: Number of *Venturia canescens* trapped with ZETA-pheromone funnel traps inside an industrial bakery processing organically grown grain

Tribolium confusum was found in the milling and the silo area, all over the year as the temperatures ranged from 28,5°C to 36,7°C. *T. confusum* is one of the main pests in mills in Germany at present. In the monitored bakery the beetle occurred in low densities. *Holepyris sylvanidis*, recorded for the first time in Berlin/Brandenburg, parasitises the larvae of *T. confusum*. The restricted growth of the population of *T. confusum* could be due to the parasitisation by the Bethylids. It is known from experiments in the laboratory that *T. confusum* accept pupae of *T. evanescens* as food (SCHÖLLER 1996). However, offering parasitised *Sitotroga*-eggs did not give any evidence of *T. confusum* preying on pupae of *T. evanescens*. Besides the fact that the release of *T. evanescens* from Tricho-cards proved to protect from predators, the handling close to machinery or in shelves was simple. The mass release of *T. evanescens* did not lead to an eradication of larval parasitoids of the pyralids.

No dermestid beetles could be found. Dermestids, as *Trogoderma angustum*, *Anthrenus verbasci,* or *Dermestes peruvianus*, which are fairly common in Berlin, could indicate the presence of remnants of dead insects. The lack of these dermestids could indicate that there was no accumulation or absence of dead insects.

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Biological control of *Anthrenus verbasci* (L.) and *Trogoderma granarium* Everts (Coleoptera: Dermestidae) with the ectoparasitic wasp *Laelius pedatus* (Say) (Hymenoptera: Bethylidae)

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ABSTRACT

Experiments were conducted at 28° C and 50 - 60 % r. h. to assess the efficacy of the ectoparasitic wasp *Laelius pedatus* (SAY) to control the larvae of the varied carpet beetle *Anthrenus* verbasci (L.) and the larvae of the khapra beetle *Trogoderma granarium* EVERTS. The female parasitoids sting and paralyze the host before oviposition. A female wasp paralyzed on average 74 larvae of *A. verbasci* compared to 44 larvae of *T. granarium* during its life span. 46 eggs were oviposited on 30 % of the paralyzed larvae of *A. verbasci*. Hence, the wasp paralyzed more larvae than those used for oviposition. When honey diluted in water (1:1) was provided to the female parasitoid, the number of host larvae paralyzed and eggs laid increased slightly.
The mortality of the host larvae was due to the venom of the wasp as well as the feeding by the parasitoid larvae. The venom of *L. pedatus* caused 100 % larval mortality in *A. verbasci* and 60 % in *T. granarium* whileparasitization caused 100 % mortality in both dermestid larvae.
Key words: Biological control, *Anthrenus verbacsi, Trogoderma granarium, Laelius pedatus*

INTRODUCTION

The varied carpet beetle *A. verbasci* and the khapra beetle *T.* granarium are widely distributed throughout the world. They infest stored animal and plant products and frequently cause great damage and losses. *A. verbasci* infests a variety of animal products such as wool, fur, leather, feathers etc. (Zacher 1932; Kunike 1938,1939; Griswold 1941). It is also the most important pest of insect collections in museums (Zacher 1927; Hinton 1945). The larvae of the khapra beetle *T. granarium* feed on a variety of plant and animal materials such as wheat, barley, rice, sorghum and maize, as well as dead insects (Hopkins 1955; Noon 1958; Lindgren & Vencent 1959). *T. granarium* causes serious damage and losses to wheat, groundnuts, cowpeas and lentil particularly in the tropics (Bhattacharya & Pant 1969; Hyward 1984; Geisthardt 1992).

Infestations by the two dermistids are usually controlled by treatments with insecticides. However, insecticides may cause hazards to man and the environment. Especially in the storages of small subsistence farmers in the tropics the use of insecticides may be dangerous and their costs prohibitive. Hence, there is a need for the development of alternative methods such as biological control, which under certain conditions could be an efficient component in integrated pest management. The ectoparasitic wasp *L. pedatus* is known to attack host larvae of some dermestids especially *Anthrenus* and *Trogoderma* spp (Mertins 1980; Klein and Beckage 1990). The common host of this wasp is the varied carpet beetle *A. verbasci* (Mertins 1980). Some other species of dermistids may also be accepted as hosts. However, the rate of parasitism varies from one host species to another. The wasp was found to prefer the host larvae of *Trogoderma variabile* Ballion compared to larvae of *T. glabrum* (Herbst) (Klein & Beckag 1990) and *T. angustum* (Solier) to *T. granarium* (Al-Kirshi et al. 1996).

The present study was designed to assess the effectiveness of the parasitoid *L. pedatus* in controlling *A. verbasci* and *T. granarium* .

MATERIALS AND METHODS

Insect Rearing

A. verbasci

The stock used for the experiments was obtained from the insect culture of the Institute for Stored Product Protection. The insects were reared in climatic cells at 20° C and 65 - 70 % r.h. with a diet of bruised wheat, fish powder and wool.

T. granarium

T. granarium larvae were obtained from a rural store in Yemen and were subsequently cultured on wheat at 30° C and 50 to 60 % r.h.

L. pedatus

The wasp culture was introduced in 1994 from Wisconsin, Madison, USA. For the experiments it was reared in plastic petri dishes on the varied carpet beetle *A. verbasci* (L.) and subsequently on *Trogoderma angustum* (Solier) by 28° C and 50 to 60 % r.h.

All experiments were carried out in climatic cells at 28° C and 50 - 60 % r.h.

Larval paralysis

10 medium-size healthy larvae of either of the two dermistid species were placed on a filter paper in 9 cm diameter plastic petri dishes in 8 replicates. One newly emerged female wasp was introduced in each dish. The host larvae were examined daily, paralyzed larvae were removed and replaced by new healthy larvae. Observations continued daily till the female wasp died. Thus, it was possible to determine the number of host larvae paralyzed by a single female.

Larval mortality due to venom

To determine the effect of the wasp venom on the mortality of the host larvae, 80 paralyzed larvae of *T. granarium* and 20 of *A. verbasci* in groups of 10 individuals of each species were placed in plastic petri dishes. The paralyzed larvae were examined weekly for mortality or survival.

Parasitization

In 4 replicates a newly emerged *L. pedatus* female was provided with 15 host larvae of *A. verbasci* in petri dishes. Weekly the wasp was transferred into a new petri dish with 15 new host larvae. The procedure was repeated until the female wasp died. Thus, the number of eggs laid and the number of host larvae parasitized by a single female were determined.
Similar experiments were conducted with an additional diet for the wasps. The diet was provided by offering a little cotton pad with a honey-water solution (1:1).

RESULTS

Paralysis

The number of paralyzed larvae of *A. verbasci* and *T. granarium* is shown in table 1. It can be seen that during its life time a female *L. pedatus* paralyzed on average 74 host larvae of *A. verbasci* compared to an average of 44 larvae of *T. granarium*.

Table 1: Number of larvae of *A. verbasci* and *T. granarium* paralyzed by a single female of *L. pedatus* during its life span (4 - 5 weeks at 28° C, 50 - 60 % r. h.)

Host	Number of paralyzed larvae
Anthrenus verbasci	73,9 ± 19,8
Trogoderma granarium	43,6 ± 10,9

Effect of the venom

The effect of the venom of *L. pedatus* on the mortality of both hosts is shown in table 2. The paralyzed larvae of A. *verbasci* did not recover from the venom and died within 3 weeks. However about 40 % of the paralyzed larvae of *T. granarium* survived the venom within 4 to 5 weeks and continued their development to adults.

Table 2: Lethal effect of the venomous sting of *L. pedatus* on the host larvae *Anthrenus verbasci* and *Trogoderma granarium* (28° C, 50 - 60 % r. h. and 4 - 5 weeks observed time)

Host	paralyzed larvae observed	mortality (%)
Anthrenus verbasci	20	100
Trogoderma granarium	80	58,75

Rate of parasitization

The number of eggs laid as well as the number of host larvae parasitized per a single female of *L. pedatus* upon the host larvae *A. verbasci* are shown in table 3. It can be seen from the table that a female laid an average of 46 eggs on 23 host larvae. When honey water was provided the numbers of eggs laid were slightly higher.

Table 3: Number of eggs laid and *A verbasci* larvae parasitized by one female of *L. pedatus* (28° C, 50 - 60 % r. h., 5 - 6 weeks life time of the female wasp)

diet	number of eggs laid	host larvae parasitized*
larvae alone	46 ± 10,00	23 ± 6,00
larvae plus honey	50 ± 05,25	27 ± 2.00

* = number of host larvae which received at least one egg

DISCUSSION

The parasitoid wasp *L. pedatus* was found to have desirable characteristics to control the varied carpet beetle *A. verbasci* and the khapra beetle *T. granarium*. The female attacks and paralyses the host larvae. The mortality of the host larvae is caused either by the venomous sting or by the feeding of the of the parasitoid larvae.

All paralyzed larvae of *A. verbasci* died within 2 to 3 weeks, but about 40 % of the paralyzed larvae of *T. granarium* could recover after 4 to 5 weeks and continued their development to adults. This may have been caused by some detoxifying mechanism of this species. On the other hand, the temporary effect of the venom is also important because it will slow down population development and reduce losses.

Besides the mentioned species, *L. pedatus* was found to paralyze and successfully parasitize other species like *Trogoderma inclusum* Leconte and *T. versicolor* (Creutzer) (Al-Kirshi et al. 1995). Furthermore, it was observed that the wasp attacks the furniture carpet beetle *Anthrenus vorax* Waterh (Al-Kirshi, unpublished). On the other hand, *L. pedatus* was unable to attack the tropical carpet beetle *Attaginus fasciatus* (Thunberg) or the hide beetle *Dermestis maculatus* De Geer (Al-Kirshi, unpublished) as well as the furniture carpet beetle *Anthrenus flavipes* LeConte (Ma et al. 1978). Larvae of *Anthrenus fuscus* Olivier were found to recover from the venomous sting within 24 to 48 h (Mertins 1982,1985).

The wasp could penetrate into wheat and successfully parasitize larvae of *T. granarium* in a depth of up to 90 cm (Al-Kirshi, in press). At the parasitoid/host-ratio of 1 : 25 the wasp could suppress the population of *T. granarium* in wheat by up to 80 % (Al-Kirshi et al. 1996).

The data obtainde show the potential of using *L. pedatus* for the biological control of *A. verbasci* and *T. granarium*. In order to achieve this this goal, practical investigations in infested grain storages will be necessary.

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Biological control of bruchids in stored cowpea in West Africa

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ABSTRACT

In West Africa, cowpea is an important crop for subsistence farmers and a major source of protein for poor people. Cowpea is stored in traditional granaries during the dry season, which may last up to nine months. Bruchids, *Callosobruchus maculatus* in particular, cause considerable losses in stored cowpea. After several months of storage the whole stock may be destroyed. Traditional control measures often fall short, especially when large quantities of cowpea are concerned. Chemical control is generally inadequate for a number of reasons. In the past, a number of alternative methods have been investigated, such as the use of plant oils, resistant cowpea varieties and hermetically closed storage of cowpea. However, for some farmers even such methods are still out of reach. For them, a conservation strategy of biological control, which aims at exploiting the sources of natural enemies that are already present in the field, may be a solution. Three species of larval parasitoids, *Dinarmus basalis*, *Eupelmus vuilleti* and *E. orientalis*, and egg parasitoids of the genus *Uscana* are indigenous to the region. A computer simulation approach will be used to explore different strategies that can be used to increase the impact of *Uscana* on bruchid populations in stored cowpea.

INTRODUCTION

Sub-Saharan West Africa is one of the poorest regions in the world. According to the United Nation's human development index, seven out of the ten poorest countries (measured by life expectancy, adult literacy and gross national product per person with purchasing power) are West African (Newton & Else, 1995). A large proportion of the population is directly involved in agriculture (e.g. some 90% in Burkina Faso; Ettema & Gielen, 1992). West Africa is also the world's major production center of cowpea (*Vigna unguiculata* Walp.). In 1996, 67% of the world's cowpea production was produced in Nigeria alone. In the same year, Africa as a whole produced 94% of the world's production (FAO, 1997; see also Nwokolo & Ilechukwu, 1996). Cowpea is an important source of protein for low income families, because it is much cheaper than meat (Nwokolo, 1996; van Alebeek, 1996).

Several features cause cowpea to be a favorable crop for the Sahel region. It is relatively resistant to dry periods (Nwokolo & Ilechukwu, 1996). Apart from the beans, the pods, leaves and stems are also used for human and animal consumption or as green manure (Duke, 1990). Symbiont bacteria that reside in the roots bind nitrogen, and growing cowpea may help improve soil fertility and soil structure.

Apart from areas where farmers have access to rivers or lakes, cowpea is grown during the rainy season. This starts in May-June and may last until August-September. There is no rainfall during the other months of the year. The typical yearly cowpea harvest of a subsistance farmer amounts to some 200 kg of threshed seeds. During the dry season, cowpea is usually stored in traditional granaries. The shape and construction of these granaries varies greatly between and even within different regions (Sagnia & Schütte, 1992). They are normally constructed of straw, wood, clay and/or other natural materials. Cowpea can be either stored in the pods or as threshed grains. Often the cowpea is stored as pods during the first few weeks or months, after which they are threshed. The price of cowpea increases during the dry season, which is one of the reasons why farmers store cowpea. Cowpea that is in a good condition at the end of the storage season is a source of income for subsistence farmers (Sagnia & Schütte, 1992).

Unfortunately, stored cowpea is often attacked by bruchids. Three species are of interest: *Bruchidius atrolineatus* (Pic), *Callosobruchus rhodesianus* (Pic) and *C. maculatus* F. (Singh et al., 1990; Jackai & Daoust, 1986). *B. atrolineatus* is mainly a field pest, as it tends to go into reproductive diapause after one or a few generations in storage. *C. rhodesianus* has quite recently been found in the coastal regions of Benin and Togo. However, the species which is responsible for most of the losses is *C. maculatus*.

Adult females of *C. maculatus* lay their eggs on ripening pods in the field. The hatching larvae eat their way into the grains, where they develop and pupate. The adult emerges from a 'window' in the bean. In a granary, the bruchids continue their lifecycle. After 6 months of storage, the stock may be totally destroyed due to feeding of bruchid larvae. At the end of the storage season it is often hard to find cowpea on the local markets that is not yet attacked by bruchids. The cowpea that is still relatively free of bruchids may have been treated with insecticides; in such a case it is possible that harmful residues are still present.

CURRENT CONTROL METHODS

A large variety of control methods against bruchids in stored cowpea is known (Van Huis, 1991; Sagnia & Schütte, 1992; Lienard & Seck, 1994). They are aimed at either preventing bruchid infestation, eliminating or minimizing bruchid populations, or a combination of these effects. The control methods can be roughly divided into three categories: traditional methods, chemical methods and alternative methods.

Traditional methods comprise the use of inert materials such as sand and wood-ash, the use of plant materials with supposed insecticidal or insect-repellent action, and other methods. Sand and wood-ash can effectively control bruchids (Javaid & Ramatlakapela, 1995; Katanga Apuuli & Villet, 1996; Ofuya, 1986). The dust or sand particles prevent bruchids to oviposit on the beans. The dust particles also damage the integument of the adults, causing their desiccation. However, larvae that are already present inside the beans can still complete their development. Advantages of these methods are that the materials used are widely available and not toxic. Disadvantages are that relatively large amounts of sand or ash are needed, which is a reason why these methods are mainly used for the preservation of small quantities of cowpea only. Another disadvantage of the use of sand is that the sand fills in the emergence holes (made by the bruchids) in the beans. It seems to be very difficult to remove this sand before cooking (Ingeborg de Groot, pers. comm.).

Leaves or other parts of various plants which supposedly control the insects are sometimes added to the cowpea stocks (Lambert et al., 1985; Ogunwolu & Odunlami, 1996; Seck et al., 1996; Rajapakse & Van Emden, 1997). However, the efficacy of these methods is not always clear, while they may require quite a lot of labor. Plant parts with relatively short-lasting insecticidal action (*i.e.,* less than three weeks) have the disadvantage that natural enemies which live outside the beans are killed, while the bruchid larvae and pupae (which reside inside the beans for up to three weeks) are left unharmed.

After harvesting, the cowpea is often first stored as pods. Only a few weeks later the beans are threshed. Storage in pods seem to offer some protection against bruchid attacks as long as the pods are not yet burst open. The reason for this is that mortality among bruchid larvae that have to eat their way through the pod wall first can be quite high (Caswell, 1984).

Chemical control methods have several disadvantages. Several pesticides do not kill the larvae and pupae inside the beans. If the action of the pesticide is only short-lived, the natural enemies might be killed, while the larvae inside the beans can still continue to develop. However, insecticides with greater persistence might pose a danger to human health. Furthermore, insecticides are generally expensive and subsistence farmers do not have those financial means. Moreover, they are often not trained in the use of pesticides. Inappropriate use of pesticides might increase the health risk and reduce the efficacy of pest control.

Scientific research concerning bruchid control at the farmer's level has opened perspectives for several *alternative methods*. Plant oils, when mixed into the beans, have ovicidal action and prevent bruchids to oviposit on the beans. Experiments have shown this to be a good control method. However, they are generally too expensive to be used in large quantities of cowpea. Neem seed oil, which has also insecticidal action, also has the disadvantage that it produces an unpleasant flavor.

Cowpea varieties that have some level of resistance against bruchids have been developed. Such resistance can be based on physical and physiological factors (e.g. Oigiangbe & Onigbinde, 1996). However, such resistances may easily be broken even in a few bruchid generations (Shade et al., 1996). Often farmers still prefer the old varieties.

A very elegant control method is that of storage in hermetically closed plastic bags or oil drums. This kills all insects that are present by suffocation, and it prevents reinfestation as long as the system remains closed. Storage in two or three layers of firmly closed solid plastic bags ('triple bagging') is already recommended by plant protectionists in several countries. In this case it is of vital importance that rodents cannot damage the bags. Sometimes the triple bagging method is combined with a simple solarization technique before storage, which kills the insects much faster. The bags can be used several times; and no toxic substances are involved. However, many farmers in the Sahel region have no access even to such simple things as a few solid plastic bags. To store 200 kg of threshed cowpea seeds, one oil drum or 8-12 large plastic bags are needed (in the case of double or triple bagging). These materials are simply not always available and are also quite expensive.

BIOLOGICAL CONTROL OF BRUCHIDS

For several years already, researchers have been investigating the possibilities of biological control of bruchids in stored cowpea. In the case of cowpea storage, there is a high level of tolerance for insect presence, and cosmetic demands are low. These attributes give occasion to the investigation of the possibilities for biological control (Haines, 1984). There is, however, a major constraint: The infrastructure in the countries involved is relatively poor, and farmers generally lack financial means. Therefore, it will be impossible to implore mass rearings of beneficial organisms. Any biological control program will have to fit into the existing socio-economical framework.

Three different strategies of biological control can be distinguished: Classical biological control, inundation and conservation. In the case of classical biological control an exotic natural enemy is imported from abroad and released; after its release it should establish and reduce the population levels of the pest organism. This can be of interest especially when the pest organism is imported as well. Successful examples of this kind of biological control are abundant. In the case of inundation, beneficial organisms are reared on a large scale and released on a regular basis. A well-known example is the control of greenhouse whitefly with the parasitic wasp *Encarsia formosa*. A conservation strategy of biological control is aimed at conserving the populations of natural enemies that are already present. This can be achieved by e.g. providing extra shelter and additional food sources. Since *C. maculatus* is indigenous to West Africa, and because efficient natural enemies occur in the same region, a conservation strategy is the most appropriate in this case.

The most important natural enemies of the bruchids of cowpea are three larval parasitoids and an egg parasitoid (Van Huis, 1991). The larval parasitoids are *Dinarmus basalis* (Rond.) (Hymenoptera: Pteromalidae), *Eupelmis vuilleti* (Craw.) and *E. orientalis* (Craw.) (Hymenoptera: Eupelmidae) (van Alebeek, 1991; van Alebeek et al., 1993). Of these, *D. basalis* seems to be the most efficient species. However, interspecific competition between *D. basalis* and *E. vuilleti* has been observed. *E. vuilleti* is a facultative hyperparasite of larvae of *D. basalis*, which causes that a combination of both parasitoids is less effective in the control of bruchids than either species alone. The egg parasitoid belongs to the genus *Uscana* (Hymenoptera: Trichogrammatidae) (Lammers & Van Huis, 1989). Although the taxonomy of this genus is not yet clear, the species that parasitizes the bruchids of cowpea has previously been referred to as *Uscana lariophaga* Steffan. However, it is possible that actually several species are involved. In this paper I will refer to the egg parasitoids as *Uscana* spp.

Because the egg parasitoids are very small (approximately 0.4 mm long), they are easily overlooked, especially when compared with the larval parasitoids. However, their impact on bruchid populations may be quite large. Previous research has shown that natural mortality due to *Uscana* can be as high as 50% (Lammers & Van Huis, 1989). From a theoretical point of view egg parasitoids have the advantage that they kill the bruchids in the egg stage, while larval parasitoids allow the bruchid still to consume part of the bean before they kill it.

FUTURE RESEARCH

Ultimately, the research on *Uscana* spp. at our department is aimed at exploring possibilities of increasing the impact of *Uscana* spp. on bruchid populations in stored cowpea. This will hopefully enable us to propose new ideas for the control of the bruchid pests.

Previous research has focused on foraging behavior, the role of bean and bruchid odors in host location, and functional response of *Uscana* spp. (e.g. van Alebeek et al., 1996; van Alebeek, 1997). In the near future, a computer simulation approach will be employed to investigate research questions that are related to the conservation strategy of biological control.

There seem to be three different ways in which the *Uscana* populations could be conserved and supported. First, the storage environment (granary structure or content) could be manipulated in such a way that the average temperature or the temperature extremes are altered. Secondly, selectively offering of extra food to *Uscana* might have an effect on population levels. In laboratory experiments it has already been found that *Uscana*'s that were allowed to feed on honey lived up to five times longer and had a fecundity that was three times as high as compared to the control (Maes, 1990). In granaries, extra food could be offered by adding cut flowers in gauze bags to the beans. Finally, it is known that *Uscana* spp. also parasitize bruchids that occur on wild leguminous trees and shrubs. These are not necessarily the same species, but there are indications that they are also capable of parasitizing eggs of bruchids of cowpea. If this appears to be true, pulses of such trees could be used as easy-available sources of parasitoids for inoculation.

All three ways can first be explored by means of a simulation model. In addition, the model can be used to investigate questions that are of interest from a fundamental point of view. The model approach may also be used for other tropical systems of stored produce.

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Dispersion pattern of *Teretriosoma nigrescens* Lewis (Coleoptera: Histeridae) in traditional Togolese maize stores

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ABSTRACT

The dispersion pattern of *Teretriosoma nigrescens*, a predator of *Prostephanus truncatus*, in traditional stores of maize cobs with husks was investigated in a quarantine cage located in southern Togo. The maize had been exposed to natural pest infestation for 4 months before the cage was closed and the predator introduced. The population development and the spread of *P. truncatus* was clearly affected by the predator. The pest density was reduced by 80% after 9 months in stores with presence of *T. nigrescens* as compared to control stores. The frequency of infested cobs amounted to 63% in absence of the predator and was reduced to 35% in its presence. The predator spread very quickly and effectively into the cobs infested by *P. truncatus*. Already after 1 month, 81% of infested cobs were colonized by *T. nigrescens* and the maximum colonization rate was 98% after 6 months. The numerical dispersion of the population of *T. nigrescens* in infested cobs changed remarkably during storage. At the beginning of the storage most of the cobs were colonized by little numbers of *T. nigrescens* ranging from 1 to 10 individuals. After 9 months the highest frequency was detected for cobs colonized by 21-50 adult predators.

Key words: *Prostephanus truncatus*, *Teretriosoma nigrescens*, predator, traditional maize stores.

INTRODUCTION

The predator *Teretriosoma nigrescens* Lewis (Coleoptera: Histeridae) has been introduced into Africa to control *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae), a serious pest of maize and dried cassava chips (Helbig, 1995). This pest was accidentally introduced into Africa, presumably with maize from Central America. The first record of *P. truncatus* came from Tanzania at the end of the 70th (Dunstan and Magazine, 1981) the second from Togo at the begin of the 80th (Harnisch and Krall, 1984). Today the pest occurs in many countries in East, West and Central Africa (Hodges, 1994).

Losses in traditional maize stores increased dramatically after the introduction of the pest (Hodges et al., 1983; Pantenius, 1987). The traditional method of storing maize as cobs with husks favors the pest and makes the control more difficult and less effective (Cowley et al., 1980; Richter et al., 1997). The main reason for the problems caused by this pest in Africa was thought to be the lack of natural enemies in the new habitat (Hodges, 1984). Therefore the predator *T. nigrescens*, which had been found in Central America and showed a high potential to control the pest in several studies (Rees, 1985, 1987; Böye, 1988; Leliveldt and Laborius, 1990), was introduced into the new infestation area of the pest (Helbig, 1995). In the present investigation, population dynamics and dispersion of the predator were studied in traditional maize stores erected in a quarantine cage in southern Togo.

MATERIAL AND METHODS

The investigation was carried out on the experimental site of the „Service de la Protection des Végétaux“ in Lomé-Cacaveli in 1989/90. Maize cobs are usually stored with husks in an open granary called „Ebli-va“ in southern Togo (Pantenius, 1988; Helbig, 1995). In August 1989, six stores of the “Ebli-va” type were erected on the platform of the test cage and 200 kg of a local, yellow-grained maize variety was stored in each. The maize was exposed to natural pest infestation for approx. 12 weeks, then removed from the stores, systematically mixed and finally restored.

The quarantine cage (W x L x H: 5 x 9 x 2.5 m), which was build of metal gauze, was divided into two halves along its length, without any connection between them. Four cells behind each other were contained in each half. The first cell (1.5 x 2.5 m) was for transfer, the 3 following cells (2.5 x 2.5 m) were test cells (3 repetitions of one treatment) containing one store each. On December 18th, 1989, the 2000 adult *T. nigrescens*, which had been reared and checked according to quarantine regulations at the Federal Biological Research Centre for Agriculture and Forestry in Berlin, Germany, were introduced into each of the three stores of this treatment.

One hundred cob samples were taken in 30 day intervals according to the method described by Pantenius (1988) and fumigated with PH3 before evaluation in the laboratory. The samples were evaluated using the cob-by-cob method which yields all data for insect populations and for loss assessment for each cob separately (Pantenius, 1988). Insect populations were investigated by counting the adult individuals present in cobs.

The number of adult *P. truncatus* and *T. nigrescens* was classified into categories to analyze the dispersion of both insects. The categories were as follows: category 1: no beetle; 2: 1-2 beetles; 3: 3-4; 4: 5-10; 5: 11-20; 6: 21-50; 7: >50. The development of the infestation by *P. truncatus* during storage is represented by the percentage of infested cobs in the samples. A cob was classified as infested if at least 3 adults of *P. truncatus* and 1 damaged grain were present.

RESULTS

The maize had been exposed to natural infestation for approximately 4 months before the cage was closed and the predator introduced into the stores. Therefore the pest had enough time to infest the maize and to establish a population. After an initial storage period of 3 months with numbers of adult *P. truncatus* nearly similar in both variants the effect of the predator on population development of the pest became clearly visible (Fig. 1). In absence of *T. nigrescens* the number of adult *P. truncatus* increased to approx. 3700 beetles after 9 months. As compared to this the population of the pest reached only approx. 800 adults in presence of the predator. The population of *T. nigrescens* multiplied from a few beetles per 100 cobs at the beginning up to approx. 900 adults after 9 months.

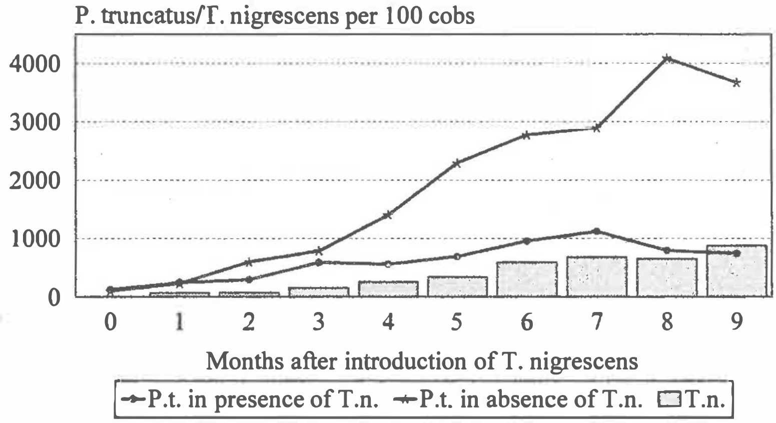

Fig. 1: Population development of *Prostephanus truncatus* (P.t.) and *Teretriosoma nigrescens* (T.n.) in traditional maize stores located in the quarantine cage (long storage period 1989/90; mean values of 3 repetitions)

To demonstrate the dispersion of *P. truncatus* within a maize store the percentage of infested cobs was calculated. A cob was classified as infested, if at least 3 adults and 1 damaged grain were present. In stores without the predator the percentage of infested cobs increased from 8 % at the beginning up to 63 % after 9 months (Fig. 2). The dispersion of the pest was clearly reduced in stores with presence of *T. nigrescens*, where 35% of cobs were infested at the end of the experiment.

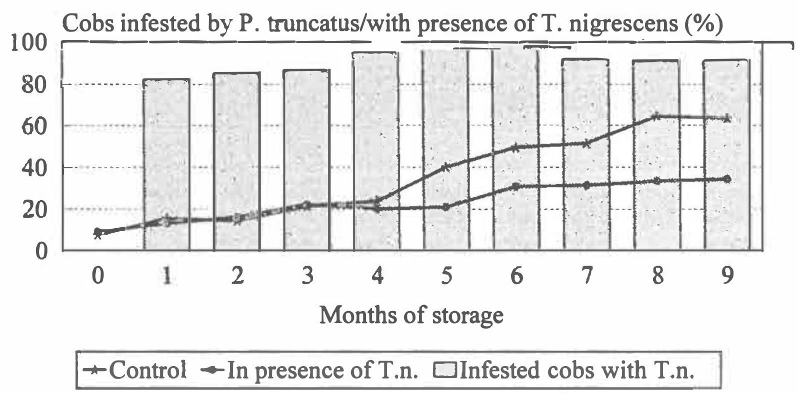

Fig. 2: Effect of *Teretriosoma nigrescens* (T.n.) on the frequency (%) of cobs infested by *Prostephanus truncatus* in traditional maize stores in the quarantine cage and presence of the predator in infested cobs (long storage period 1989/90; mean values of 3 replicates)

The dispersion of the predator is demonstrated by the percentage of cobs infested by *P. truncatus* and colonized by *T. nigrescens*. Already one month after the introduction, *T. nigrescens* was detected in 81% of infested cobs. The predator continued spreading into infested cobs in the following months and his presence reached a maximum of 98 % after 6 months.
To analyze the numerical dispersion of *T. nigrescens* in cobs infested *by P. truncatus,* the cobs were classified into categories. These categories were differentiated by the number of adult *T. nigrescens* present. After 1 month of storage most of the infested cobs were colonized by small numbers of *T. nigrescens* and only a few cobs with high numbers occurred (Fig. 3). During the storage, frequencies of cobs in categories of lower density decreased while those in categories of high numbers increased. After 9 months the highest frequency was detected for cobs colonized by 21-50 adult *T. nigrescens*.

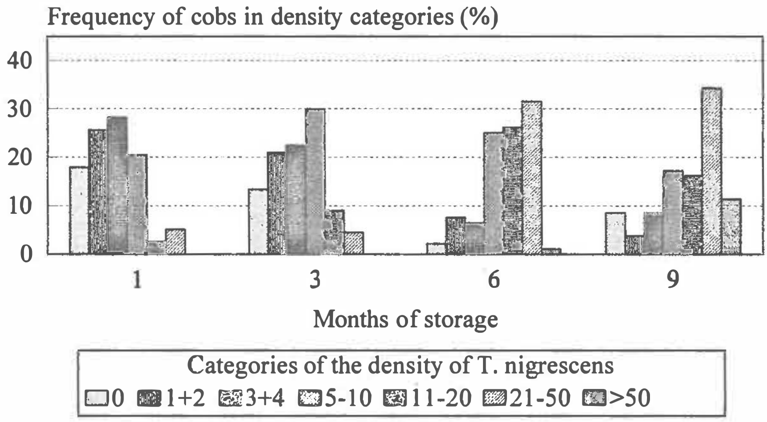

Fig. 3: Dispersion pattern of *Teretriosoma nigrescens* (T.n.) in cobs infested by *Prostephanus truncatus* in traditional maize stores in the quarantine cage (long storage period 1989/90; mean values of 3 replicates)

An additional way to analyze the response of the predator to host dispersal and host density in cobs is presented in table 1. The frequency for every combination of predator and prey category was calculated to show the efficacy of dispersion and the correlation in numbers of beetles. The most frequent cobs were those with absence of both insects. In total, 310 cobs (=11,5 %) were counted with presence of the predator in absence of *P. truncatus*. Most of these cobs (88.7 %) were colonized by only 1 or 2 beetles. On the other hand, some 414 cobs (=15.3 %) with absence of *T. nigrescens* but presence of the pest were detected.

Tab. 1: Number of maize cobs in combinations of categories for the density of *Prostephanus truncatus* (P.t.) and *Teretriosoma nigrescens* (T.n.) in traditional maize stores in the quarantine cage (long storage period 1989/90; counts for all sampling data and the 3 repetitions)

Categories for	P. truncatus								
T. nigrescens	0	1+2	3+4	5-10	11-20	21-50	>50	Sum	%
0	1192	343	35	26	7	3		1606	59.5
1+2	275	129	30	34	18	6		492	18.2
3+4	29	20	6	42	31	16	2	146	5.4
5-10	5	7	12	37	44	51	7	163	6.0
11-20	1	1	3	24	31	52	17	129	4.8
21-50			1	12	29	55	41	138	5.1
>50				1	5	10	10	26	1.0
Sum	1502	500	87	176	165	193	83	2700	
%	55.6	18.5	3.2	6.5	6.1	7.1	2.9		100

DISCUSSION

The investigation showed that *T. nigrescens* was able to suppress *P. truncatus* effectively under semi-practical conditions in the quarantine cage. Population development of the pest was clearly reduced as compared to the control. This effective control was obtained despite the 4 months period of undisturbed pest infestation and development before the predator was introduced into the stores. The results confirm previous studies carried out on maize grains in glass jars which showed a high potential of *T. nigrescens* to control *P. truncatus* under laboratory conditions (Rees, 1985, 1987; Böye, 1988; Leliveldt and Laborius, 1990).

The number of adult *T. nigrescens* increased remarkably during the storage period. This indicates that no substantial hindrances in environmental conditions, such as temperature and humidity, occurred. Furthermore, this increase in population density of the predator shows that it was able to respond to the population density of the prey already present in the stores. A quick reduction of the pest population was very important under the experimental conditions, because the pest population was already established in the stores.

In contrast to studies on maize grains, where access to the prey is relatively easy, the control in the case of cob storage is more difficult. The predator has to search in each cob for possible infestation. Since each cob could be regarded as a little, more or less closed habitat, an effective pest control is only possible if the population of *T. nigrescens* spreads into the greater part of infested cobs. Otherwise the pest would develop undisturbed in a high number of cobs which would allow a substantial increase in density.

Two observations indicate possible reasons for the good effectiveness of the predator. One important factor is assumed to be the quick spread of *T. nigrescens* into the infested cobs. Already one month after the introduction, 81% of infested cobs were colonized by the predator. During storage the dispersion of the predator continued and a maximum of 98 % presence in infested cobs was reached. This high dispersal activity is an important factor in effectiveness of the predator because it assures that the number of cobs where the pest could develop in peace is kept small.

The other factor which might have influenced the effectiveness of the predator is the numerical dispersion of the population in infested cobs. At the beginning of trial, just after the introduction, *T. nigrescens* dispersed in a high number of cobs but with only a few individuals in each. This strategy of colonization allows a high reproduction rate and a low mortality of premature stages due to the availability of high prey numbers per predator specimen and the lack of competition. From the point of view of pest control it maximizes the killing rate per individual predator. Later in storage the population of the predator increased which resulted in higher numbers per cob and in colonization of newly infested cobs.

However, these results also show the limitations of the biological control with *T. nigrescens*. In total some 414 infested cobs were found during the 9 months of storage without the presence of the predator. Furthermore, even at the end of the trial, when the number of predators exceeded the number of pest individuals, some infested cobs were not colonized by *T. nigrescens*. This shows that control will always fail for a certain number of cobs. First results obtained in studies under natural conditions confirmed the high potential of *T. nigrescens* to control *P. truncatus* (Mutlu, 1994). Further investigations over several years will be necessary to show which degree of pest control and loss reduction could be reached by this control strategy.

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Biological efficacy of some commercial and isolated varieties of *Bacillus thuringiensis* on the development of *Cadra cautella* (Walker) and *Tribolium confusum* Jacqueline du Val on stored crushed corn

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ABSTRACT

Most of the stored product insect pest species are beetles, which in both the larval and adult stage are destructive. The control of these beetles using a bacterial formulation is an exciting area of research. In this study investigations on the isolates E-AS 16A (*Bacillus thuringinensis* Berliner var. *indiana*) and E-AS16B (*Bacillus thuringinensis* var. *morrisoni*) showed that the isolates are active against moth and beetle pests of stored grain, respectively. Each of these isolates led to some biological effects in *Cadra cautella* and *Tribolium confusum* fed on crushed corn treated with these isolates at median and sublethal doses. These effects induce retardation in larval and pupal development, reduction in adult emergence, egg production and hatchability. The efficacy was found comparable with that of commercial products used against these species.

Key words: *Cadra cautella. Tribolium confusum*, *Bacillus thuringiensis*, median lethal dose, sublethal dose.

INTRODUCTION

Cadra cautella (Walker) and *Tribolium confusum* Jacqueline du Val are major pests of stored corn and its commodities. Experts figure that the post harvest losses due to stored product insect pests in tropical areas range from 5 to 30 % for cereal grains whereby losses on a commercial level are generally seen as more crucial than on farm level.

Several workers found that *Bacillus thuringiensis* controls stored product moths (Yamvrias, 1962; van der Lean and Wassink, 1964; McGaughey, 1976; Merdan and Harein, 1984; McGaughey, 1986).

The possibility of exposure of stored product insects to a median and sublethal concentration of the bacterial pathogen was evaluated.

The present study aims to determine the effect of the median and sublethal concentrations of α-exotoxin of *Bacillus thuringiensis* of some isolates from Egyptian stored grain fauna and some commercial strains, on the development of two stored product insects, the almond moth, *Cadra cautella*, and the red flour beetle, *Tribolium confusum*.

MATERIAL AND METHODS

Insect culture

Insect species used were taken from laboratory cultures maintained at 27±3°C and 65±5% relative humidity (RH) and a photoperiod 16:8 (L:D). Both insect species were raised on crushed corn. In case of *C. cautella*, the jars containing the culture were provided with a piece of cardboard for resting and oviposition of females. The third instar larvae were used for experimentation.

Bacterial culture

The *Bacillus thuringiensis* (*B.t.*) isolates, E-AS 16A and E-AS 16B have been isolated from the Egyptian stored grain dust fauna in a previous work. These isolates have been identified by the Division de la microbiologie, gouvernement du Quebec, Ministère de Resource Naturelles, Direction de la recherche (Forâte), Canada. The first isolate was identified as *B.t.* var. *indiana* and the second as *B.t.* var. *morrisoni*. The commercial formulation, M-one (*B.t.* var. *sandiego* was kindly provided by Mycogen corp.; Trident (*B.t.* var. *tenebrionis*), was kindly provided by Sandoz crop protection corp. and Foil (*B.t.* var. *kurstaki*) and Cutlass (*B.t.* var. *kurstaki*) were kindly provided by Ecogen INC.

Laboratory essay

All the bacterial isolates: E-AS 16A, E-AS 16B, M-one, Trident, Foil, Cutlass and the standard formulation HD-1-S-1980 were tested against both target insects. In case of *C. cautella,* larvae were tested at five concentrations ranging between 500 and 4 µg/g of crushed corn. In case of *T. confusum*, larvae were tested at five different concentrations ranged between 10000 and 320 µg/g of crushed corn. Three replicates were used for each concentration, with ten larvae in each cup. A control experiment was run at the same time without *B.t.* toxin for each experiment. All cups of both experiments were held at 27± 3°C and 65 ± 5% RH. The cups were checked daily and mortality counts were made after 7 days and corrected for control mortality. The data were analyzed using "Stat" program for probit analysis.

The development of larvae of both insect species was determined on the crushed corn at a median and sublethal dose of the most effective isolates for each species. Larval and pupal duration, larval wet weight and percent of moth emergence were recorded. After emergence pairs of adults were kept in glass tubes and the longevity of both sexes, adult wet weight, egg production and percent of hatching were recorded for each species in the control and in treated samples.

RESULTS

Attempts were made to determine the activity of the different bacterial isolates used in this laboratory assay against third instar larvae of *C. cautella* and *T. confusum*. From these attempts it was found that in case of *C. cautella* only the isolates Standard, E-AS 16A, Cutlass and Foil gave mortalities above 50%. In case of *T. confusum* only the isolates E-AS 16B and Foil gave mortalities above 50% at the tested dosages. No activity was recorded for the other tested isolates.

LC_{50}-values produced by probit analysis, as well as 95% confidence limits, slope, variance and potencies of the active isolates are shown in Table 1 for *C. cautella.*

Table 1: Effect of the *Bacillus thuringiensis* varieties under investigation against target insect species.

Insect species	Isolate or strain trade name	variety	LC_{50} (μg/g)	95% conf. Limits	Slope ± S.E.	Variance	Potency	Fold increase
Cadra cautella								
	- Standard	kurstaki	45.80	20.01-7.22	1.22 ± 0.46	0.0920	16000	-
	- EAS-16A	indiana	20.38	20.92-19.84	1.37 ± 0.63	0.00003	35957	2.25
	- Cutlass	kurstaki	12.48	8.10-16.63	2.43 ± 0.78	0.0839	58718	3.67
	- Foil	kurstaki	48.24	37.66-58.83	1.33 ± 0.001	0.0023	15191	0.95
Tribolium confusum								
	- E-AS 16B	morrisoni	2500	1490-3378	2.45 ± 0.95	0.0034		
	- Foil	kurstaki	4125	2015-14320	1.56 ± 0.86	0.0125		

The isolate E-AS 16A *(B.t.* var. *indiana*) gave an LC_{50} of 20.38 μg/g compared to 45.80 μg/g of the standard formulation, which equals to a 2.25-fold increase in potency. Among the commercial strains Cutlass (*B.t.* var. *kurstatki*) gave the highest activity with an LC_{50} of 12.48 μg/g, corresponding to a 3.67-fold increase of potency. The commercial product Foil (*B.t.* var. *kurstaki*) gave the least activity with LC_{50} of 48.24 μg/g. On the other hand, assessment with *T. confusum* showed that only the isolates E-AS 16B. (*B.t.* var. *morrisoni*) and Foil (*B.t.* var. *kurstaki*) showed activity causing mortalities of 67% and 52%, with a LC_{50} of 2500 μg/g or 4125 μg/g, respectively.

Data on the effects of the tested *B.t.* varieties on the development of the almond moth are given in Table 2. This clearly showed that the use of the median lethal dose and sublethal dose of the isolate E-AS 16A and the commercial products Cutlass and Foil significantly prolonged the larval and pupal duration compared to the control, with the effect of Cutlass being most pronounced. The larval wet weight at the end of the larval period was reduced to 15.80 ± 0.73, 10.81 ± 4.24 and 19.35 ± 2-65 at the median lethal dose of E-AS 16A, Cutlass and Foil, respectively, compared to 62.70 ± 6.94 for the control. A sublethal dose was found to significantly affect the wet weight of the surviving larvae. Moth emergence was 88% in the control. This was reduced to 21 and 40% when the larvae were fed crushed corn treated with a median lethal or sublethal dose of the isolate E-AS 16 A. The effect of Cutlass in this concern was greatly pronounced being 16 and 19% for the median and sublethal dose, respectively, compared to 57 and 80% at these dose levels for Foil. The adult longevity showed no significant effect at the median lethal dose of the isolate E-AS 16A. Egg production was significantly reduced in the females reared on median and sublethal doses of E-AS 16A, Cutlass, and Foil. Also, the percentage of hatching was significantly reduced and the effects of Cutlass was the most pronounced.

For *T. confusum* the data in Table 3 show that larval duration and pupal duration was significantly affected at both the median lethal and sublethal doses of both the isolate E-AS 16B (*B.t.* var. *morrisoni*) and Foil (*B.t.* var. *kurstaki*) compared to the control which had a larval duration of 27.18 ± 0.43 days and pupal duration of 3.4 ± 0.04 days. The larval and pupal wet weight of the surviving insects seemed not to be affected at both isolates although the beetle emergence was significantly reduced to 57.5 and 43.90% at the median lethal doses of E-AS 16B and Foil, respectively, compared to 92.5% in the control. This was increased at the sublethal doses to 81.3 and 60.24%, respectively. Data on fecundity and fertility showed that Foil greatly reduced egg production of the females reared as larvae on crushed corn treated with median lethal dose, the reduction was also significant with the median and sublethal doses of the isolate E-AS 16 B, the fertility of the eggs showed no effect compared to the control. On the other hand, the doses of Foil used had significantly reduced it.

DISCUSSION

The results obtained revealed that the isolates E-AS 16A (*B.t var. indiana*) and E-AS 16B (*B.t. var. morrisoni*) that were isolated from Egyptian stored grain dust fauna gave promising results, compared to commercial products, on the prolongation of larval and pupal periods, on the percentage of moth and beetle adult emergence and also on fecundity and fertility of the surviving insects. On the other hand, these isolates may be of value in controlling some other species of moths and beetles of stored product commodities, as well.

Table 2: Effect of the isolates and commercial products of *B. thuringiensis* on the development of *C. cautella* on stored crushed corn.

Item studied / Isolate & conc. used (μg/g)	Larval+Pupal duration (days) mean ± SE	Larval wet wt. (mg) mean ± SE	% Moth emergence	Adult wet wt. (mg) mean ± SE	Adult longevity (days) M. m ± SE	Adult longevity (days) F. m ± SE	Egg Production/F mean ± SE	% of Hatching
Control	36.00 ± 0.88^{a} **	62.70 ± 6.94^{a}	87.5	2.72 ± 0.39^{a}	5.60 ± 0.32^{a}	6.01 ± 0.24^{a}	160 ± 8.45^{a}	98.13
Isolate								
- E-AS 16A								
(Mld)* : 20	43.40 ± 1.02^{b}	15.80 ± 0.73^{b}	21.25	0.81 ± 0.07^{b}	3.40 ± 0.05^{b}	4.25 ± 0.83^{b}	95.5 ± 7.60^{b}	63.78
(Sld)* : 8	41.7 ± 0.65^{b}	24.18 ± 1.02^{c}	40.00	1.11 ± 0.16^{a}	5.21 ± 0.64^{a}	4.12 ± 0.30^{b}	101.12 ± 16.37^{c}	78.40
Commercial Products								
- Cutlass								
(Mld) : 12	54.7 ± 0.55^{c}	10.81 ± 4.24^{b}	16.42	0.63 ± 0.57^{b}	5.61 ± 0.29^{a}	5.95 ± 0.11^{a}	88.90 ± 10.90^{b}	56.36
(Sld) : 4	48.40 ± 0.21^{d}	15.50 ± 0.27^{b}	19.25	1.08 ± 0.31^{a}	5.42 ± 0.09^{a}	6.0 ± 0.45^{a}	95.83 ± 3.64^{b}	58.64
- Foil								
(Mld) : 48	49.80 ± 0.27^{d}	19.35 ± 2.65^{b}	57.24	1.19 ± 0.05^{a}	5.55 ± 3.20^{a}	3.16 ± 2.12^{a}	99.12 ± 10.80^{d}	65.95
(Sld) : 16	49.25 ± 0.83^{d}	33.53 ± 5.24^{d}	80.01	1.90 ± 2.13^{a}	5.36 ± 0.01^{a}	5.60 ± 0.7^{a}	120.20 ± 3.59^{c}	83.67

* Mld = Median Lethal dose
Sld = Sublethal dose
** Means followed by the same letter are not significantly different within the same column, levels of significance was tested at 1%.

Table 3: effect of the isolates and commercial products of *B. thuringiensis* on the development of *T. confusum* on stored crushed corn

Item studied / Isolate & conc.used(μg/g)	Larval duration mean ± SE	Pupal duration mean ± SE	Larval wet wt. (mg) mean ± SE	Pupal wet wt. (mg) mean ± SE	% Beetle emergence	Adult wet wt. (mg) mean ± SE	Egg Production/F mean ± SE	% of Hatching
= **Control**	27.18 ± 0.43^{a**}	3.4 ± 0.04^{a}	2.26 ± 0.15^{a}	3.16 ± 0.02^{a}	92.5	1.91 ± 0.07^{a}	150.0 ± 0.95^{a}	100
= **Isolate**								
- E-AS 16B								
(Mld)* - 2500	40.17 ± 5.30^{b}	7.20 ± 1.4^{b}	1.66 ± 0.17^{b}	2.28 ± 0.10^{a}	57.5	1.46 ± 0.11a	62.87 ± 6.94^{b}	90
(Sld) - 780	35.25 ± 1.14^{b}	4.16 ± 0.89^{c}	2.03 ± 0.20^{a}	2.40 ± 0.15^{a}	81.3	1.57 ± 0.02^{a}	73.0 ± 4.13^{b}	96
= **Commercial products**								
- Foil								
(Mld) -4125	42.65 ± 0.90^{b}	9.69 ± 2.16^{d}	0.90 ± 0.05^{c}	1.22 ± 0.70^{b}	43.90	1.20 ± 0.08^{a}	53.12 ± 4.65^{d}	69
(Sld) - 1640	37.25 ± 3.12^{b}	8.58 ± 3.24^{d}	1.02 ± 0.19^{a}	1.20 ± 1.22^{b}	60.24	1.85 ± 0.91^{a}	68 ± 6.40^{b}	77

*Mld = Median Lethal dose
Sld = Sublethal dose
**Means followed by the same letter are not significantly different within the same column, levels of significance was tested at 1%.

The results showed also that the median and sublethal doses of the active strains of *B.t.* influences the foregoing generations of both insect species from different aspects decreasing adult emergence, reducing fecundity and prolonging the generation period. These may be also reflect the effects of the toxins on larvae of both species before pupation, especially at the median lethal doses used. From these results, it appears that the resulting damage due to exposure of both insect species to median and sulbethal doses may be as significant for effective control as immediate death. Similar findings have been reported by previous authors (McGaughey and Kinsinger, 1978; McGaughey, 1976, 1978) with *P. interpunctella* and *C. cautella* treated with *B.t.* var. *kurstaki*; (Dulmage et al., 1978) with *Heliothis virescens* treated with *B.t.* var. *entomocidus*; (Salama et al., 1981) on three species of cotton pests, *Spodoptera littoralis*, *S. exigua* and *Heliothis armigera*; (Salama and Sharaby, 1988) with *Agrotis ypsilon* treated with *B.t.* var. *kurstaki* and *B.t.* var. *entomocidus* (Salama et al., 1991) and with *P .interpunctella* and *Sitotroga cerealella* treated with both the S-endotoxin and the β-exotoxin of *B.t.* var. *kurstaki*.

From these results it could be concluded also that the efficacy of the indigenous isolates E-AS 16A and E-AS 16B was comparable to that of the commercial products.

On the other hand, the isolated E-AS 16B showed important results with the beetle species used. Although, the strains of the commercial products against Coleoptera did not have any activities on the species used or even the lepidopteran species. Also, the isolate E-AS 16A was recorded by the author for the first time in the stored grain fauna. It is hoped that this isolate, possessing high activity against other harmful coleopteran and lepidopteran stored grain insect pests, will be usefull for more effective field applications in the future.

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The effect of food supplements on the longevity of the bean weevil parasitoids *Anisopteromalus calandrae* and *Heterospilus prosopidis.*

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ABSTRACT

The effect of artificial food sources on the longevity of the bruchid parasitoids *Anisopteromalus calandrae* and *Heterospilus prosopidis* was investigated. Adult parasitoids were provided with water only, or exposed to either honey, uninfested cowpeas, or *C. chinensis* infested cowpeas (either containing weevil eggs or larvae).
Nectar was the only treatment to enhance the longevity of *H. prosopidis*, increasing the parasitoid's average lifespan by a factor 5.7. In the case of *A. calandrae* both honey and larvae infested cowpeas increased the parasitoid's longevity by a factor 6.6 and 4.0, respectively. The implications of these findings for the use of food supplements in storage systems are discussed.

INTRODUCTION

In stored product protection, there is an increasing interest in the development of biological methods for pest control (van Huis, 1991; Brower et al., 1995). The advantages of using beneficial insects to combat storage pests have only recently become widely recognized (Gordh and Hartman, 1991; Brower et al., 1995). They do not leave synthetic residues on the stored commodities, are safe to non-target organisms, the chance of pests developing resistance is low, the antagonists either occur naturally or can be applied safely by unskilled workers and they can be self perpetuating, ensuring prolonged control of the stored product. In farm-stored or bulk-stored products, that are cleaned before human use, it has been shown that parasitoids or predators do not contribute to insect fragments in the processed commodity (Harris et al., 1953). Still, in certain biological control systems the level and the reliability of control may be insufficient (van Lenteren, 1980). It has been recognized that we can improve upon the effectiveness of biocontrol by adjusting field or storage conditions to the specific ecological needs of the beneficial organisms (Lewis et al., 1990), e.g. by providing suitable food supplements (Wäckers, 1994; Jervis et al., 1996).

Most (if not all) adult parasitoids feed on sugar sources, such as (extrafloral) nectar and honeydew (Jervis et al., 1993). In addition to this nectar feeding, a large number of parasitoid species feed on the haemolymph of their hosts. In some of these host feeding species, nectar is the sole food source during early adult life, whereas host feeding occurs only after the ovaries have developed sufficiently (Flanders, 1935). Taking into account that host feeding species usually complement their diet with sugars, nectar feeding can be said to be ubiquitous. The fact that host feeding is usually confined to female parasitoids, whereas both male and female parasitoids feed on nectar (Leius, 1960), further underlines the general importance of nectar feeding.

Nectar feeding can have strong effects on parasitoid fitness parameters. Not only are sugar meals indispensable to parasitoid survival (Zoebelein, 1955; Syme, 1975; Idoine and Ferro, 1988), well-fed parasitoids have also been demonstrated to be more active and more focused in seeking out their herbivorous hosts (Telenga 1958; van Emden, 1963; Wäckers, 1994; Takasu and Lewis, 1995). In some parasitoids, nectar feeding has furthermore been demonstrated to increase the female's lifetime egg production, either through an increase in the rate of egg maturation; an increase in reproductive lifespan, or both (Zoebelein, 1956; Hocking, 1967; Syme, 1975). Each of these three fitness parameters is directly linked to the number of hosts a parasitoid can attack, and thereby to its effectiveness as a biological control agent.

Lack of suitable food sources in man-made ecosystems has long been suspected to be an important cause of failure in biological control programs (e.g. Illingworth, 1921; Wolcott, 1942; Hocking, 1967). It has taken considerable time, however, for this basic concept to be translated into attempts to employ food supplements to enhance the effectiveness of natural enemies. Under field conditions, two basic strategies of food provision can be distinguished: firstly, provision of food sources through habitat diversification (Powell, 1986; Bugg et al., 1987; Altieri, 1994; Orr and Pleasants, 1996; van Rijn and Tanigoshi, 1997), and secondly, dissemination of artificial food supplements, either sugar sprays (Evans and Swallow, 1993; Weseloh, 1995) or sugar solutions with protein supplements (Hagen et al, 1971; Hagen, 1986). The majority of these reported attempts have proven successful in raising natural enemy populations and reducing pest populations. Despite the promising results under field conditions, the concept of food supplements has yet to be extended to post harvest systems.

In the study presented here, we investigated the effect of food supplements on the longevity of the parasitoid species *Anisopteromalus calandrae* (Hymenoptera: Pteromalidae) (Howard) and *Heterospilus prosopidis* (Hymenoptera: Pteromalidae) (Viereck). The polyphagous solitary parasitoid *A. calandrae* has been identified as one of the most promising candidates for biological control of a wide range of storage pests, including maize weevils, rice weevils, the grain moth (*Sitotroga cerealella*) and several *Bruchidae* in beans (Ghani and Sweetman, 1955; Brower et al., 1995). The solitary ectoparasitoid *Heterospilus prosopidis* is known to attack a broad range of *Bruchidae* among which *Acanthoscelides* spp., *Bruchus* spp., *Callosobruchus* spp., *Caryedon* spp. and *Zabrotes subfasciatus* (Marsh, 1979; Kistler, 1985).

MATERIAL AND METHODS

Cowpeas (*Vigna ungiuculata* [L.]) were obtained from Haeflinger (Herzogenbuchsee, Switzerland).

Callosobruchus chinensis (Howard) (Col: Bruchidae) had been reared on cowpeas for more than 50 generations. In order to obtain bruchid eggs or larvae of controlled age for the experiments, weevils were allowed to oviposit on uninfested cowpeas during a period of 24 hours. Subsequently cowpeas were sifted to remove the weevils and were subsequently kept in plexiglass containers for different periods of time according to date of emergence. Climatic conditions were controlled at 25^{0}C, 65%RH, and 16L:8D (12.500 lux).

Anisopteromalus calandrae (L.) (Hym: Pteromalidae) and *Heterospilus prosopidis* (Viereck) (Hym: Braconidae) had been reared on *C. chinensis* infested cowpeas for more than 50 generations. Upon emergence, parasitoids were placed in plexiglass containers at 25^{0}C, 65% RH, and 16L:8D (12500 lux) and provided with water only.

Two days following emergence, unfed parasitoid females were individually placed in plexiglass boxes (7x3x14 cm) containing one of the following: three drops of 1µl honey; 20 uninfested cowpeas; 20 cowpeas infested with 1 day old *C. chinensis* eggs, or 20 cowpeas infested with 14 day old *C. chinensis* larvae. In the latter two categories, the infested beans were replaced every third day to ensure that the same host stage was available throughout the experiment. Individual parasitoids placed in boxes containing water were used as a control. Twenty females were tested per treatment and the number of surviving individuals was recorded daily.

RESULTS

Anisopteromalus calandrae (Fig 1).

In the absence of food sources, parasitoids lived an average of 6.6 days. When kept with uninfested cowpeas or egg infested cowpeas, the average lifespan (8.1 days and 7.3 days respectively) were not significantly different from the control. This indicates on the one hand that parasitoids did not die from dehydration, while on the other hand it shows that they did not obtain nutritional benefits from the cowpeas themselves or from *C. chinensis* eggs.

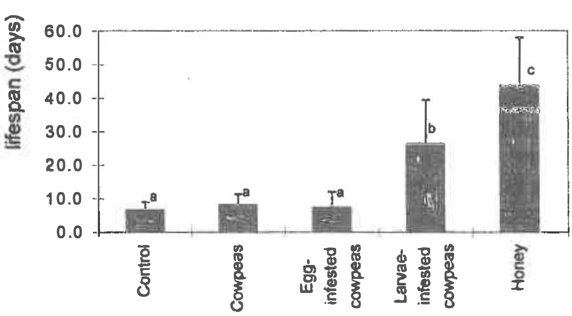

Fig 1. Average lifespan of *A. calandrae* females when exposed to various potential food sources. Different letters indicate significant differences (Bonferroni)

Longevity was considerably higher in the remaining two treatments. Honey yielded the highest longevity increment. This food supplement increased parasitoid longevity to an average of 43.8 days, which is 6.6 times longer than the control group. Parasitoids exposed to larvae infested cowpeas lived four times as long as control individuals (26.4 days). This increased longevity is due to host feeding by *A. calandrae* on the bruchid larvae (Ghani and Sweetman, 1955).

Heterospilus prosopidis (Fig 2).

In the absence of food sources, parasitoids lived an average of 14.3 days. When kept with uninfested cowpeas, the average lifespan (16.1 days) was not significantly different from the control. The same applied to parasitoids which were kept with beans carrying *C. chinensis* eggs (15.7 days) and *C. chinensis* larvae (11.6 days). This indicates that parasitoids did not obtain any nutritional benefit from either beans or hosts. Therefore, unlike *A. calandrae*, *H. prosopidis* does not engage in host feeding, which makes this species entirely reliant on sugars as a source of adult nutrition. The slight lifespan reduction in the group of individuals which had been provided with host larvae might reflect the (energetic) costs of reproduction.

Longevity was considerably higher when parasitoids were provided with honey. This food supplement increased parasitoid longevity to an average of 81.6 days, which is a factor 5.7 times longer than the control group.

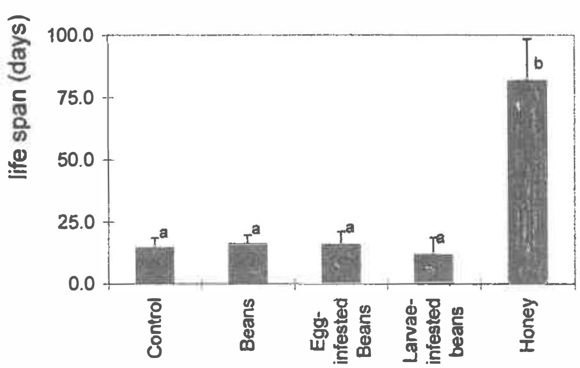

Fig 2. Average lifespan of *H. prosopidis* females when exposed to various potential food sources. Different letters indicate significant differences (Bonferroni).

DISCUSSION

While the idea of using food supplements to augment the efficacy of biological control has gained growing acceptance in field entomology, this concept has still been largely unexplored with respect to post harvest systems. To date, the only exception has been the work by van Huis et al. (1990), who studied the effect of food supplements on the longevity of the egg parasitoid *Uscana lariophaga*. They reported that the average lifespan of this parasitoid could be increased by a factor five, when provided with honey as a food source. This level of increase is within the range of longevity enhancement we found for *A. calandrae* and *H. prosopidis*. These findings show that food supplements can hold a vast potential for improving biological control efficacy in post harvest systems as well. In storage systems, the potential benefits of added food sources may actually exceed those in field systems for the following reasons:

- Under field conditions natural enemies may not be completely deprived of carbohydrate sources. Either the crop itself, or non-crop plants (weeds) within the field, or in field margins may contain (extra)floral nectaries or honeydew. Storage systems, in contrast, are generally absolutely devoid of sugar sources. Under such food depleted situations, the addition of food sources is likely to yield a more dramatic benefit to biological control efficacy.

- The extended arthropod fauna in field ecosystems represents fierce competition for the available food sources. Due to the comparatively limited insect fauna in storage areas, the competition level will be lower in post harvest systems . Consequently, a given amount of food supplements is likely to have a more pronounced effect on the target beneficials.
- The effectiveness of non-crop food plants will depend on the spatial distribution of these food plants relative to the crop. Food sources in field borders, undergrowth, or intercrops may be beyond the foraging range of natural enemies present on the crop plants. In post harvest systems, food supplements can be offered in closest proximity to the stored products.
- Under field conditions, (artificial) food supplements can be negatively affected by climatic conditions. Dew and precipitation can result in sugar sources being washed off, while high temperatures and humidity can accelerate microbial breakdown. In closed storage conditions, these negative effects can be avoided, or at least limited.

Our data for *A. calandrae* show that this species has the option to obtain energy from host haemolymph in addition to nectar feeding. Host feeding increased parasitoid longevity by a factor four, which is 60% of the increase by nectar feeding. The significantly higher longevity of honey-fed parasitoids could either reflect the nutritional differences between these food sources, or it could be due to the fact that (energetic) costs of oviposition reduced parasitoid longevity.

Even for those parasitoids that can obtain nutritional benefits from host haemolymph, the availability of additional food supplements can be vital for their reproductive fitness. In host feeding parasitoids the potential benefit of nectar availability will depend on host density and the question whether or not host feeding leaves hosts suitable for oviposition. At high host densities, when parasitoids can oviposit and host feed ad libidum, the benefit of nectar availability is expected to be moderate. Nectar feeding may further raise longevity and may provide a better energy source for parasitoid activity. However, at lower host densities, nectar availability can have strong effects on parasitoid reproductive fitness. In the (temporary or local) absence of hosts, the option of host feeding is eliminated. Under these conditions non-host food sources will contribute most to parasitoid reproductive fitness, since it allows parasitoids to survive extended periods without host encounters.

In those species like *A. calandrae*, in which host feeding makes the host unsuitable for offspring development, host feeding can interfere considerably with parasitoid reproductive fitness. At high host densities the diversion of hosts for food may only be of minor detriment to parasitoid reproductive success. However, at low host densities destruction of reproductive units through host feeding can severely limit parasitoid offspring production, with deriving repercussions for the long term effectiveness of biological control. Here again, the availability of alternative food sources could optimize biological control efficacy by shifting the balance from host feeding to parasitoid offspring production.

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Blattisocius tarsalis (Berlese), would this predatory mite be effective against moth eggs in Scandinavian flour mills ?

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ABSTRACT

The mite *Blattisocius tarsalis* is an effective predator on eggs of the Mediterranean flour moth *Ephestia kuehniella*, which is the main pest species in Scandinavian flour mills. Many facts speak for the use of this mite in a biological control program in mills, although there also exist a few limitations. This paper presents some of the main advantages and disadvantages of using *B. tarsalis* against *E. kuehniella* under conditions found in Scandinavia.

Key words: *Blattisocius tarsalis*, *Ephestia kuehniella*, effectiveness, low temperatures, biological control.

INTRODUCTION

The most serious pest species pest in the milling industry in Scandinavia is the Mediterranean flour moth (*Ephestia kuehniella* Zeller, Lep.: Pyralidae) and until now large mills have been fumigated once or twice a year with methyl bromide in order to prevent problems with this pest species. However, methyl bromide will be prohibited in Denmark and Sweden by 1 January 1998, forcing mills to rely on a combination of other chemicals or alternative methods. This could encourage the use of biological control methods in mills. In Denmark these circumstances had the consequence, that a five year study on biological control in flour mills was initiated in 1996 (Hansen, 1997). Among the different types of natural enemies egg predators and egg parasitoids are preferable in the milling industry, since they probably can suppress moth populations before any damage occurs and they are unlikely to contaminate the final product.

The predatory mite *Blattisocius tarsalis* (Berlese) (Acari: Ascidae), is a common predator on moth eggs, and it appears to be cosmopolitan in distribution, having been recorded from a number of locations (Chant, 1963; Haines, 1981). *B. tarsalis* is primarily found in connection with stored food materials (Hughes, 1976). Graham (1970) reported on the regulatory effect of *B. tarsalis,* which was regarded as the major controlling factor in suppressing an infestation of *Ephestia cautella* (Walker) (Lep.: Pyralidae) on bagged maize in a warehouse in Kenya. Further information on the biology of *B. tarsalis* may be found in Haines (1981) and in Darst & King (1969).

As *B. tarsalis* has also been found in a Danish flour mill, it has been the subject of laboratory studies in order to investigate its role as a potential biological control agent. This paper will discuss some of the main advantages and disadvantages of using *B. tarsalis* against *E. kuehniella* under conditions found in Scandinavia.

MATERIALS AND METHODS

In order to study the ability of the mite to penetrate a layer of flour, only adult female mites were used. No attempt was made to determine their age. Individuals of *B. tarsalis* were offered 3 fresh *E. kuehniella* eggs for 24 hours. The eggs were protected by a layer of 1 mm or 2 mm of wheat flour at 27°C and 1 mm at 21°C. The eggs had an age of maximum 24 hours, when the experiments were initiated. The experimental units consisted of small plastic cups (12.5 ml, Ø 25 mm) where a piece of filter paper with the eggs was placed in the bottom. The eggs were glued onto the filter paper in order to to find them at the end of the experiment. At the top, the units were sealed with filter paper and a lid with a 12 mm hole. This unit had an inside area of 31 cm^2. The flour was gently sprinkled over the bottom until the layer had the wanted thickness. The observations were made in regulated environmental chambers with a temperature tolerance of ±0.5°C, 75% r.h. and in complete darkness. After the observations the number of completely or partially deflated eggs were counted. All treatments were replicated 30 times and 10 similar treated units without mites served as control at each treatment.

RESULTS

The results are presented in table 1. At both temperatures very few of the eggs covered by flour were destroyed and the mean numbers were not significantly different (P>0.05) from numbers of destroyed eggs in the control.

Table 1. Mean per cent destroyed eggs of *E. kuehniella* in treatments, where female *B. tarsalis* were offered 3 young eggs for 24 hours. The eggs were covered by a layer of flour of various thickness.

Temp.	Thickness	% Destroyed	% Destroyed in control
27°C	2 mm	17%	23%
27°C	1 mm	15%	23%
21°C	1 mm	13%	10%
27°C	0 mm	89%	10% [a]
21°C	0 mm	83%	3% [a]

[a] Data from Nielsen (1997a).

DISCUSSION

Compared with experiments where the eggs were not protected (Nielsen, 1997a), the relatively large numbers of destroyed eggs in the control demonstrate that the eggs at 27°C were affected by the used method. With unprotected eggs more than 80% of the eggs would have been completely or partially sucked out in 24 hours. Although single mites were observed at the bottom of the experimental units, it is rather obvious that if eggs are situated under a very small layer of flour in the magnitude of 1 mm or more, they will be protected from predation by *B. tarsalis*.

The actual location of eggs of *E. kuehniella* under field conditions is not known, although Daumal & Boinel (1994) reported on the presence of interstices as the most important stimulus inducing oviposition, but still they recorded large numbers of eggs, which were not concealed. The movements of the female moths during and after oviposition in flour could result in a protection of many eggs against predation by *B. tarsalis*. The possibilities of *B. tarsalis* to penetrate into a material will certainly depend on the size of space between the particles of the food material. Graham (1970) reported that *B. tarsalis* could be found within bags of maize, even when stacked. Two earlier studies investigated the interactions between *B. tarsalis* and *E. kuehniella* in closed laboratory experiments. Flander and Bagley (1963) found that *B. tarsalis* only regulated the moth population in situations, where the thickness of food material did not exceed 8 mm. Their food material was wheat kernels which were lightly tamped. White and Huffaker (1969) working with an initial food (rolled oats) material thickness of 5.3 mm, demonstrated a gradual suppression of moth populations over a long period.

A biological control program against *E. kuehniella* in Scandinavian flour mills should probably be initiated during spring and the actual temperature in the mill at that time is an important factor. Recordings of the temperatures in two Danish mills have revealed that temperatures between 10-20°C are common at that time in many parts of the mills (Hansen, 1997). Consequently it is necessary to study the behaviour of the natural enemies in this temperature regime.

As mentioned by many authors *B. tarsalis* is a very active predator. With a simple method, Nielsen (1997b) investigated the activity of adult female mites at temperatures of 7-13°C. He demonstrated that above 12°C all mites were highly active, walking more than 1.5 cm per minute. *B. tarsalis* is a phoretic mite, and is thus carried around attached to the adult moths (Flanders & Badgley, 1963; Graham, 1970). This, together with its high activity level will increase the ability of the mite to encounter the eggs of *E. kuehniella* in the environment.

A detailed study by Haines (1981) on the biology of *B. tarsalis* at 27°C / 73% r.h. demonstrated that the potential rate of increase of *B. tarsalis* far exceeds that of *E. cautella* under the actual conditions. The situation at lower temperatures is not known. Haines (1981) also found that this species can develop on alternative prey species, but his study with eggs from *E. cautella* and *Tribolium castaneum* (Herbst) showed that *B. tarsalis* displays a strong preference for moth eggs. With fresh eggs from *E. cautella* he found, that at 27°C a mean number of whole-egg equivalents of 1.5 and 2.4 were consumed per individual per day by mated not ovipositing and ovipositing females, respectively. Working with eggs of *P. interpunctella* at 25°C, Darst and King (1969) found an average number of 1.2 eggs consumed per female.

Nielsen (1997b) studied the mean daily food consumption rates of female *B. tarsalis* at different temperatures. He found that the food consumption below 13°C was very low. At temperatures of 13-21°C the mean consumption rate was around 1.6 whole egg equivalents in 24 hours. At temperatures of 23-27°C the mean consumption rate was around 2.3 whole-egg equivalents in 24 hours. The mean total number of destroyed eggs at temperatures above 11°C was high, ranging from 3 to 5 eggs per day. The high number of destroyed eggs were caused by the fact that the mean numbers of partially consumed eggs were higher than the ones which were totally consumed. Nielsen (1997a) studied the influence of different densities of young *E. kuehniella* eggs on the predation rate of female *B. tarsalis*. He found that the food consumption rate was near its maximum at 27° when the mites were offered 10 eggs for

24 hours and that the number of destroyed eggs per day possible did not reach its maximum under the same conditions.

With the present knowledge of *B. tarsalis* it cannot be determined, if this mite will be effective in a biological control program against *E. kuehniella* in Scandinavian mills. Where the eggs of *E. kuehniella* are situated under natural conditions in a flour mill and how effectively *B. tarsalis* finds these eggs are among the questions, which will have to be investigated. Furthermore, a determination of the developmental time and fecundity at temperatures between 15-20°C is relevant and the importance of the age of the prey on the consumption rate needs to be clarified. Furthermore, it would be relevant to study the possible interference with eggs parasitized by *Trichogramma*-species. Before a mass-production of *B. tarsalis* can take place it is desirable to find a method for long-term storage of this mite. Nevertheless, the present knowledge has demonstrated that *B. tarsalis* is a very interesting mite, since females are highly active down to 12°C and destroy large numbers of moth eggs above this temperature, given they do not have problems locating the eggs. These factors make the mite interesting for Scandinavian mills, as low temperatures in the spring probably would inhibit many other species of natural enemies of *E. kuehniella*.

In the milling industry in Denmark an augmentative release strategy could be useful, as the population size of adult male *E. kuehniella* increases from nearly zero to its maximum within two months in mills not using insecticides (Nielsen, 1997c). As pointed out by Haines (1984) the effectiveness of an augmentative release strategy depends on the timing of augmentation in relation to the moth's life-cycle and population increase.

As it is very difficult to make realistic semi-field experiments with this species, the evaluation of the potential role of *B. tarsalis* against eggs of *E. kuehniella.* will have to rely on laboratory experiments supported by computer simulations of different types of release strategies. Hopefully this will lead to well-planned field experiments with releases of *B. tarsalis* in flour mills, which could document the effectiveness of this mite species as asked for by Brower et al. (1996).

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Personal experience with biological control of stored food-mites

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ABSTRACT

Biological control has been developed and proven effective against mites of stored grain and seed. The predator used is *Cheyletus eruditus* (Schrank), a predatory mite which is commonly found in stores. Biological control can be used as a preventive measure in empty stores and to prevent or repress pest populations on grain or seed. The predator has lower susceptibility to organophosphates than its prey. Differences in susceptibility were also found among different strains of *C. eruditus*. Fifty percent of the predator population could survive temperatures of +2°C for 60 days and eight percent were found to survive these conditons for 200 days without loosing the ability to reproduce. Food preferences of *C. eruditus* were proven in laboratory experiments. Biological control of stored food mites is the only biological control method practically used in the stores today. The predatory mites are mass reared and sold under the commercial name CHEYLETIN.

Biological control has been developed and proven effective against mites of stored grain and seed by Pulpán and Verner in 1965. In their revolutionary work the authors proved for the first time that biological control of stored food mites using the predator *Cheyletus eruditus* (Schrank) really works in the grain stores, and they also determined under which circumstances. *C. eruditus* may be introduced at any time of the year provided the pest mites are present but not already approaching the abundance level that would make fumigation necessary. In winter the grain is too cold for *Cheyletus* to be active. However some of predators will survive to reproduce in the spring. If grain is mechanically cleaned on the conveyors, it is necessary to reintroduce the predators, as they are usually eliminated with the dust and other debris, because they live outside of the grain seeds. Biological control usually fails when acaroid mites are too abundant, namely over 1000 specimens per kilogram of grain. If the infestation level is too high, fumigation can be used and soon after the grain is aerated it is possible to introduce *Cheyletus*. Preventive application of the predators is also possible, when the grain is not infested by the mites. The authors recommended that the predatory mites can be collected from grain stores, where after the biological control has been completed, natural reservoirs of predators occur.

C. eruditus is commonly found in stores in association with acaroid mites on which it normally feeds. It has reportedly attacked, on occasion, caterpillars, psocids and springtails, i.e. prey much larger than itself. *C. eruditus* orients by movement of the prey when hunting. It was observed in the laboratory attacking iron dust which was moved by magnetism in a way like natural prey. When movement of iron dust was too fast the predator took a rather defensive position. It was also found in laboratory experiments that *Cheyletus* has food preferences among mites. Fast moving mites are preferred to slow moving ones. In stores however, it is the slow *Acarus siro* L. which is consumed first and the fast moving *Lepidoglyphus destructor* (Schrank) usually escapes. Apparently there are many factors involved in food discrimination in this species, one of them can be a niche where all three species meet. This may be connected with the food of *A. siro* and *L. destructor* or with the ability to develop a hypopus stage. *A. siro* is a primary pest, which is able to feed on undamaged seeds, whereas *L. destructor* is a secondary pest, feeding on organic dust, hyphi of fungus or fragments of seeds. *A. siro* does not form hypopus stages as easily as *L. destructor*. Hypopus are immobile stages (in case of *Lepidoglyphus*) and *Cheyletus* cannot consume them.

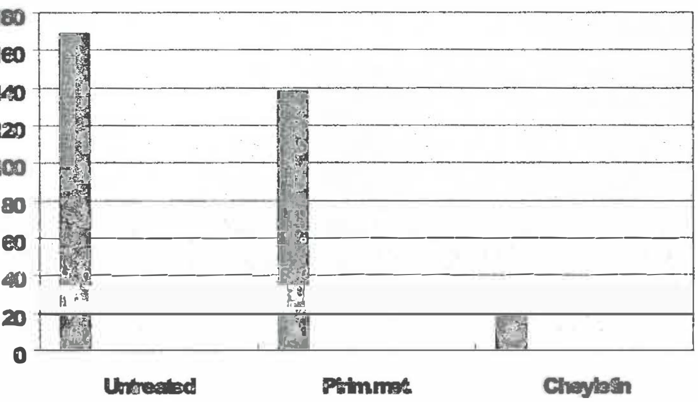
When we tried to put the method of biological control into practice, the main problem was the availability of the of predators when needed. As Pulpán and Verner (1965) suggested, store-keepers and personnel engaged in pest control had to look for natural reservoirs, sieve them out of the grain and use them for biological control. The idea was good, but the method was laborious and time consuming. When the reservoir of predators was found and there was no immediate use for them, all the effort was in vain. Therefore Zdárková and Pulpán (1973) tested survival of the predators at temperatures ranging from -1.7 to +2°C and relative humidities of 80-90 %. The best results were obtained at + 2°C. Fifty per cent of the population of predatory mites survived for 62 days, and eight per cent for 200 days without losing their ability to reproduce when transferred back to favorable conditions. Populations obtained from natural reservoirs and preserved under low temperatures could be thus used for the biological control of stored product mites latter. However, even this improvement did not provide the ultimate solution. It became clear that the technology of mass rearing of the predators has to be developed in order to use the method of biological control on the large scale.

In an attempt to develop such a technique Zdárková (1986) used *A. siro* as the food for *C. eruditus*. The main goal was to obtain as many predators as possible in the shortest period of time, but the final population of predators should not contain *Acarus* specimens. (It would not be justifiable to spread acaroid mites into stores.) The most tricky problem was the choice of the right substrate. The author tried different materials such as grain, oilseeds, clover seed, wooden chips mixed with wheat germs, etc. *A. siro* could develop almost on everything, however, the final blends of the mite populations were different. In most cases, good numbers of the predators were obtained but they were heavily mixed with the acaroid mites. Or, on the other hand, the final population was devoid of *Acarus* but with a few predators only. Out of all the substrates tested, lettuce seeds appeared to be the best. The recommended procedure of mass rearing involved batches kept in paper bags on 100g of lettuce seed at a temperature of 25°C and 75% R.H. If the initial predator: prey ratio is 1:100 to 1:200, within 28 to 35 days each batch yields an average of 2 000 to 3 000 predatory mites without any additional care. The batches can be either used directly in infested stores or kept at low temperature for a latter use.

As soon as the problem of the mass production of the predators was solved, there was no more problems to use biological control method everywhere.

The biological control stayed aside the attention of scientists throughout the eighties. In 1990 Zdárková and Horák were looking for the original source of infestation of the grain stores by acaroid mites. They found that the mites survive in crack and crevices, in the remnants of grain dust almost in every store and become a source of infestation of freshly loaded grain. When the predatory mites were applied on the floor of empty grain stores, the grain remained clean without any acaroid mites for the next two years. This preventive application appeared to be the best and cheapest use of biological control (Fig.1).

Fig.1. Number of acaroid mites per m^2 in untreated stores and in stores treated with pirimiphos-methyl and Cheyletin.



Instructions for a repressive use of biological control on stored grain had already been known, a preventive method of biological control in empty stores as well as on stored grain was elaborated. However, it was soon found that biological control did not succeed in silos. The problem was the rather low temperature during storage. For fast reproduction the predators need at least 18°C. To solve the problem a project was initiated with the aim to select cold resistant mites. They have been reared for six years now. Even though the predators can reproduce at this low temperature, time necessary to complete a life cycle is still very long lasting over one hundred days compared with 40 and 18 days at 18° and 25°C respectively. We hope that sometimes this cold-adapted population will be used in cold silos.

As it was already said biological control can only be repressively used when infestation of acaroid mites is lower than 1 000 specimens per kg. When it is higher, it is necessary to use chemical control first in order to suppress the pest population.

Zdárková and Horák (1987) found during field experiments that the predatory mite *C. eruditus* is more resistant to organophosphates than the acaroid mites. A total mortality of the predators was not observed after application of any organophosphates tested at the doses sufficient to kill 100 % of the acaroid mites. On the bases of these results Zdárková (1994) did some laboratory experiments with the aim to test the effectiveness of conventional organophosphates (pirimiphos-methyl, chlorpyriphos-methyl, chlorpyrifos) on laboratory strains of *A. siro, T. putrescentiae* and *C. eruditus*. She found that the predators were the least susceptible of all the mite species tested. The author also tested and compared different strains of predatory mites, found in the nature and in the stores (Zdárková,1997). She found great differences in their susceptibility to the tested organophosphates. Table 1 shows that strain SS_3 (the one which survived fumigation by PH_3) was the only strain resistant to all organophosphates tested, whereas SS_2 was resistant to pirimiphos-methyl and chlorpyrifos-methyl and NS_1 to chlorpyrifos.

The use of the least acaricide - susceptible populations of *C. eruditus* is most desirable in the biological management of acaroid mites. Such a strain will be mass reared and used for dissemination in the grain stores for biological control of acaroid mites.

Table 1. The resistance factors of strains of *C. eruditus* for several organophosphates at the LT_{50} and LT_{95} values.

Acaricides	*LT*	SS_1	SS_2	SS_3	NS_1	NS_2
PM EC50	50	0.89	2.27	1.77	1.14	1.19
	95	1.27	4.12	3.22	1.85	1.45
PM EC 25	50	1.06	2.17	1.38	1.19	1.62
	95	1.03	5.58	2.36	1.03	1.67
CHP	50	1.15	0.89	1.51	2.15	0.93
	95	1.52	1.76	4.63	3.34	1.25
CHPM	50	1.21	1.61	2.00	1.39	1.33
	95	1.71	3.84	3.91	1.67	1.59

Explanations: PM EC50 : Pirimiphos-methyl EC 50 (1%)
PM EC 25 : Pirimiphos-methyl EC 25 (1%)
CHP : Chlorpyrifos (1%)
CHPM : Chlopyrifos-methyl (0.1%)
LT : Lethal time

Strains : SS_1 storage strain, SS_2 storage strain from Thailand, SS_3 storage strain, which survived fumigation by PH_3, NS_1 field strain from grassland, NS_2 field strain from pheasant fodder

Brady (1970) studied the mites of poultry litter in poultry houses. He found some phytophagous species as well as predators there including several species of the genus *Cheyletus*. We have never tried biological control of mites in the poultry litter. However, the idea is quite interesting and not without chances. We observed *Cheyletus* consuming mesostigmatic mites, parasites of snakes in a terrarium.

Helbig (1996) speculated that the main reason why no biological measures are as yet actively employed in Europe are high requirements for food quality. Food must not be contaminated with unhygienic or foreign substances. The presence of filth from dead insects therefore excludes the use of beneficial organisms for biological control. The irony of such arguments is that dead pest specimens which remain in the food after fumigation are not considered to be a contamination.

It is clear that biological control cannot be applied always and everywhere. It has some specialities which have to be considered. However, especially the use of biological control in empty stores for the prevention of pests has a great potential.

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Biology of Pests and Antagonists

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Megaselia scalaris (Loew) (Dipthera, Phoridae), a new potential pest of stored foodstuffs in the mediterranean countries

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ABSTRACT

In central Italy, the tropical scuttle fly *Megaselia scalaris* (Loew) is increasingly often found both in the wild and inside buildings, suggesting that this species is now well acclimated not only in a coastal area of the Tuscany but also in other parts of the Mediterranean region.
Given its ease and speed of passive dispersal, the markedly eclectic nature of its trophic habits and the very short time span required in optimal conditions for completion of its life cycle, it seems likely that this species could become a new pest of stored foodstuffs in Southern Europe as well.

INTRODUCTION

Among Diptera Phoridae, the genus *Megaselia* contains the largest number of species and is of major interest both for basic and applied research, on account of the considerable variation in its biological behaviour. Several very common species characterized by a marked tendency to become cosmopolitan also show a surprisingly broad variety of food preferences. Although extensive saprophagy and sarcophagy on dead tissue appear to constitute their basic trophic habit, these species will readily shift to phytophagy or occasional parasitism on other arthropods, even to the point of secondary myasis on mammals (Robinson, 1971).

This group includes *Megaselia scalaris* (Loew), a species of tropical and subtropical origin which has now become cosmopolitan. In the past often misidentified[1] and commonly considered a scavenger, it can be reared easily and rapidly, and is therefore also used as a laboratory animal.

The purpose of this paper was to report on my numerous captures of this species in the wild in the coastal part of Tuscany (Central Italy), starting from summer 1993. It appears to have become well acclimated in this area, and is frequently found inside buildings in search of new trophic substrates.

Its presence is easily detectable. It is fairly large in comparison with the other representatives of the same family, with the female, which is larger than the male, reaching up to 3 mm in length. Furthermore, *M. scalaris* is distinguished by a general yellowish color on the body, broken only by wide brown bands at the urotergites (see fig. 1).

[1] On the synonymy, see Johal & Disney, 1994.

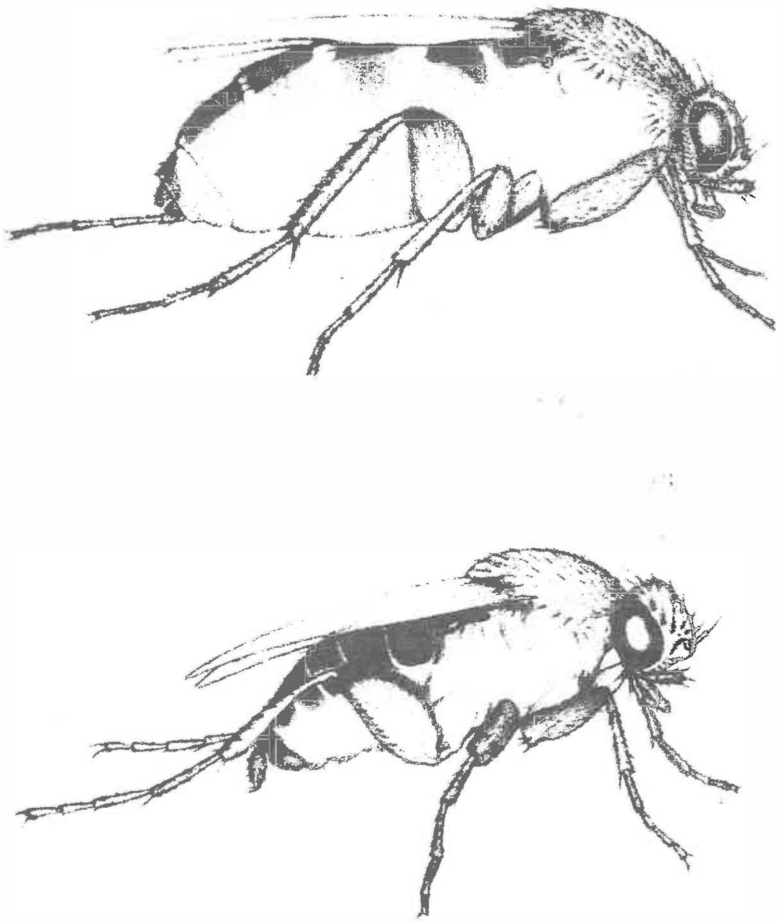

Fig. 1 – *Megaselia scalaris* (Loew). The female (above) and the male (below) (drawn by L. Santini).

European Distribution and Records in Italy

Disney (1994, pers. comm.) has suggested that the occasional records of *M. scalaris* in Britain and in other central and northern European countries (see Disney, 1991a) are clearly due to introduction by man. Overall, apart from its frequent occurrence in ships' cargoes, records show it to be restricted to laboratory cultures.

For the European Mediterranean area, so far the only reliable data on its presence in nature come from Italy. As early as 1914, Grandi, working at Portici near Naples, carried out a detailed morphological study of the larva of this species, indicated with the synonym of *Aphiochaeta xantina* (Speiser), using live material found inside dead insects sent to him from Lagos (Nigeria) by Prof. Silvestri. Many years later, further morphological studies and some biological observations were undertaken on the same species by Semenza (1946). She based her study on material multiplied in the laboratory from a few wild individuals collected in Naples and which Semenza herself believed originally arrived from a more distant location in a cargo of fruit.

It is only much more recently that I have been able to collect numerous specimens of this species in Central Italy. My observations have shown that it is now thriving in the wild and is well acclimated.

I found *M. scalaris* both as larvae and adults for the first time in 1993 and then repeatedly throughout the following years, in a vast coastal area extending between the cities of Livorno and Viareggio. The species was particularly frequent in apiaries, where its larvae, together with and in competition with larvae of several Sarcophagid diptera (*Sarcophaga* spp.), fed on the bodies of dead bees and on the large amount of organic debris that accumulates on the tray at the bottom of the hives (Santini, 1995 ; Santini & Pinzauti, 1995). I also found *M. scalaris* feeding on carrion such as the dead bodies of slugs (*Limax flavus*, *L. maximus*) and snails (*Helix aspersa*, *H. aperta*) in the same geographic area.

Despite these predominant necrophagous habits, I successfully reared this species a number of times from sporophores of different species of edible mushrooms and truffles such as *Boletus edulis*, *Tuber albidum, T. borchii* and *T. rufum*. This confirmed the findings of Disney (1991b) and Johal & Disney on *M. scalaris* as a primary parasite of mushroom cultivations. In addition, my observations showed that *M. scalaris* was capable of behaving as a primary phytophage. Eggs are laid on the carpophore when the latter is still immature. The larvae accelerate carpophore decay and decomposition, resulting in severe economic loss.
Finally, *M. scalaris* has recently also been found in the southern-most area of Italy, on the island of Linosa, in the Sicilian channel (Raspi, 1995).

Basic Features Explaining the Success of *Megaselia Scalaris*

Serious attention should be paid to the demonstration that *M. scalaris* is now stably present in a new geographic area. Certain features of its biological and behavioral pattern, described below, confer on this species a remarkable adaptive success, leading to adverse effects on some aspects of human production.

1- EASY DISPERSAL - For dispersal beyond its original area, *M. scalaris* is above all dependent on extraneous factors of passive transport.

As regards medium and long-distance transfer, which is more and more frequently encountered today, the most important modern means of transport such as aircraft, ships' cargoes trains, trucks and automobiles play a major role. This means that *M. scalaris* can be transported not only as larvae and adults, but also as pupae attached to fixtures and cargo containers. This is additionally favored by the tendency of adults of this species to remain in the immediate vicinity of infested material. When disturbed and forced into exposed situations, the adults seek to avoid flying; instead, with rapid foot movements they creep into the deepest cracks and hide.

2- CATHOLIC FEEDING HABITS - The numerous reports in the literature together with my personal observations on *M. scalaris* feeding habits indicate that the larvae, commonly considered saprophagous, are capable of developing on a wide variety of substrates. They are most frequently reported as scavengers, particularly on insect carcasses. There is however considerable evidence that this species can also complete larval development in animal feces, culture media, milk and a wide variety of fresh and decaying animal and vegetal material (Disney, 1994 ; Robinson, 1975 ; Zuska, 1968). Finally, *M. scalaris* seems to be able to develop even in extreme conditions, as for instance in boot polish (Lever, 1994) and in an emulsion paint (McCraw, 1967). In contrast, some reports concerning the parasitism of this species seem questionable, and are dependent on the fact that it can sometimes attack wounded insects.

The ability of adults to frequent different types of substrates within a relatively brief lapse of time implies the risk of contamination of human food. Furthermore, *M. scalaris* may act as a carrier of bacterial and fungal diseases and crop parasites. Johal and Disney (1994) reported this phorid as a primary parasite of oyster mushroom in India, stating that the main economic damage caused to crops is due to a secondary infestation with an indefinite bacterium transmitted by adult females and responsible for discoloration, collapse and rapid deterioration of fruiting bodies. A recent survey in Britain suggests there may be a correlation between phorid infestation and the mushroom diseases caused by fungi (White, 1993).

Finally, personal observations in the wild and in the laboratory have demonstrated that *M. scalaris* can also function as a carrier of other foodstuff pests. This typically occurs through phoresy when adults shift from a trophically exhausted to a new intact substrate. Thus I have often noticed that large egg-laying *M. scalaris* females can transport not only adults of Macrochelid mites (*Macrocheles sp.*) but also numerous migrant hypopial instars of Acarids belonging to the genus *Acotyledon sp.*, with the transported elements fixed to the intersegmental membranes of the female abdomen. While Macrochelid mites are known to feed on young larvae of saprophagous diptera, an infestation resulting from the above-mentioned Acarids can seriously damage foodstuffs.

3- RAPID DEVELOPMENT- Primarily a warm-climate species, *M. scalaris* can easily survive cooler climates of the Southern European region by infesting indoor resources. Over-wintering is guaranteed in the critical periods by the presence both of adult individuals, mainly females, and hidden inactive pupae hiding deep inside narrow cracks adjacent to previously infested substrates.

Resumption of activity and emergence appear to be closely linked to temperature and the photoperiod. Overall, the population trend is seasonal. Personal observations in Central Italy suggest that the species is evident only in summer and virtually disappears in winter. Despite this, the relatively short summer period during which this species can complete several generations and become a pest is amply compensated by the speed at which embryonic and post-embryonic development is carried out.

Table 1. Fecundity and length of single phases of life-cycle of *Megaselia scalaris*, reared under artificial diet conditions, during the summer period, at constant temperature of 27° C (mean values).

Number of eggs laid per fertile female		391	(El-Miniawi & Moustafa, 1965)
		345	(Personal observations, 1995-96)
Eggs hatching period	hours	24	(Robinson, 1975)
		17	(El-Miniawi & Moustafa, 1965)
		17	(Personal observations, 1995-96)
Post-embryonic period	days	7.5	(Robinson, 1975)
		5.5	(El-Miniawi & Moustafa, 1965)
		7	(Personal observations, 1995-96)
Pupal period	days	14	(Robinson, 1975)
		11.5	(Semenza, 1953) (23° C)
		9	(El-Miniawi & Moustafa, 1965)
		10	(Personal observations, 1995-96)
Length of life-cycle	days	18	(Semenza, 1953) (23° C)
		18	(El-Miniawi & Moustafa, 1965)
		19	(Personal observations, 1995-96)
Longevity of the adult	days	7.3 🕘	(El-Miniawi & Moustafa, 1965)
		17.3 🕚	

Values referring to the individual stages of its life cycle as reported in the literature or obtained by personal observations are shown in Table 1. The large number of eggs laid per female, the very short life cycle and the high percentage of egg hatchability and emergence of adults from pupae confirm this phorid's high potential for development under favorable conditions.

In the wild, *M. scalaris* larvae are in competition with larvae of other saprophagous diptera (e.g. Muscidae, Calliphoridae and Sarcophagidae) that may be found sharing the same substrate. When resources are limited, the success of *M. scalaris* would appear to be assured by its notably more rapid larval development (Disney, 1994).

Closing Remarks on the Economic Importance of *Megaselia Scalaris*

At the present time, available references in the literature combined with personal observations in nature in Tuscany support the statement that *M. scalaris*, as a primary feeder, like other phorid species, represents a genuine pest. It can cause serious damage to certain types of high commercial value mushrooms, both prior to harvesting and during distribution.

Furthermore, the wide catholicity of its feeding habits and the pronounced tendency of all saprophagous species to infest foodstuffs make it highly probable that *M. scalaris* can also attack packaged products, whether of vegetal or animal origin, on condition that they have sufficient moisture content. Certain types of fresh fruit and vegetables are likely to be particularly at risk. For example, in Texas *M. scalaris* has been identified as responsible for primary attacks on ears of green corn. In addition, Disney (1994) reported that on numerous occasions he personally observed food packages that were infested by *M. scalaris* larvae at the time of their arrival in England from foreign countries, including vermicelli and soy meal from Singapore, spaghetti from Italy and dates from Iraq.

Finally, the possibility that this species may be involved in the transmission of food-related infections in man and may contribute to the spread of other pests should not be dismissed out of hand.

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The biology of *Lariophagus distinguendus*: a natural enemy of stored product pests and potential candidate for biocontrol

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ABSTRACT

Lariophagus distinguendus (Förster) is a larval ectoparasitoid of at least 11 beetle species. Most of the hosts are pests of stored products, a fact that makes *L. distinguendus* a potential candidate for biocontrol in stored product protection. Studies in an olfactometer demonstrate that host finding in *L. distinguendus* is not random, but that females use volatile cues from host and host substrate for orientation and improve their response to stimuli by learning. Own studies and literature data demonstrate a great variation in the fecundity and the life span of females of *L. distinguendus*, depending on the host reared upon, host substrates, rearing conditions and the strain used. Numerous studies on *L. distinguendus* dealing with important aspects for the evaluation of natural enemies in biocontrol as well as own results indicate that *L. distinguendus* could be a promising candidate for biocontrol. Now field experiments under storage conditions are required to test this assumption.

Key words: biocontrol, stored product protection, parasitoid, reproductive capacity, strain, host finding

INTRODUCTION

Lariophagus distinguendus (Förster) (Hymenoptera: Pteromalidae) is an ectoparasitic larval parasitoid. Up to now 11 beetle species from 5 families are known as hosts, most of them pests of stored seeds or seed products (Steidle & Schöller, 1997). This fact makes *L. distinguendus* a potential candidate as natural enemy in biocontrol for the protection of stored foodstuffs.

Prior to the selection of a predator or a parasitoid species as natural enemy for biocontrol, knowledge about its biology is essential. Therefore this study deals with some aspects of the biology of *L. distinguendus*, its fecundity and its host finding behaviour. These aspects are very important for the evaluation of natural enemies in biocontrol in stored product protection (see Kidd & Jervis, 1996; van Alebeek, 1996).

MATERIAL AND METHODS

Data on the general biology of *L. distinguendus* were taken from the literature. All experiments were performed at 25°C and 60-70% r.h. For rearing conditions refer to Steidle and Schöller (1997). To study life span and fecundity of *L. distinguendus*, one female and one male within 24h after emergence from the grain were placed in petri dishes containing 5g (about 100 grains) of wheat grains infested by 15-30d old larvae of the granary weevil

Sitophilus granarius (L.). The petri dishes were checked daily for dead individuals and the offspring was counted after emergence. Two different strains of *L. distinguendus* „Berlin II" and „Uzwil" were examined. Further data were obtained from literature. For details of host finding studies see Steidle and Schöller (1997). Female parasitoids from the strain „Uzwil" were placed in the gauze walking arena of a four chamber diffusion olfactometer with the odor samples and controls underneath. The allocation time in the sectors above the samples was registered and compared to the controls. The females studied were either inexperienced, i.e. they had been kept isolated since emergence, or experienced, i.e. they had been kept on infested grains and had numerous contacts with hosts and oviposition experience. The samples tested correspond to the potential volatile sources that could attract the parasitoids to grains infested by granary weevil larvae: fæces of the weevil larvae (F), material from infested grains which was cleaned from fæces (IGO), longitudinal cut grains to imitate grains which had been mechanically damaged by feeding larvae (DG), healthy grains (HG) and weevil larvae (L).

RESULTS

The host stages preferred by *L. distinguendus* are older larvae (LIII-LIV), prepupae and pupae (van den Assem, 1971; Kashef, 1955). *L. distinguendus* is an ectoparasitoid. The eggs are laid on the host which lives inside a cocoon or a seed (Hase, 1924). The parasitoid larvae then feeds from outside on the host. From the 8th day on the parasitoid larvae pupates and from the 17th day on the males emerge from the seed or cocoon. The females start to emerge one day later (Gonen & Kugler 1970).

Host finding experiments in an olfactometer revealed that inexperienced females were attracted only by the fæces of the hosts (F, Table 1). Material from infested grain was only slightly attractive and all the other samples were not attractive at all. For experienced females on the other hand not only the fæces (F) were attractive but also samples from the grains: material from infested grains without fæces and larvae (IGO), the mechanically damaged grains (DG) and the healthy grains (HG). The host itself, the weevil larvae (L), was not attractive to inexperienced females and to experienced females.

Study of literature and own experiments revealed large differences in fecundity and life span depending on host the parasitoid was reared upon, host substrate and strain used (Table 2). Fecundity data of 3 different strains, that were all reared on *S. granarius* with no additional water or food, differed widely, ranging from the strain "Berlin II" that is almost unable to develop on larvae of *S. granarius* over the strain "Uzwil" to the strain "Leiden" with up to 160 descendants per female. The difference between the "Leiden" strain and the other strains probably is much higher, because studies on the "Leiden" strain were obtained at 18°C, where oviposition in *L. distinguendus* is suppressed (Ryoo *et al.*, 1991).

DISCUSSION

Except for one unpublished study (Cho, 1989, cited in Ryoo *et al.*, 1991) there are no studies were *L. distinguendus* has been used for the control of storage pests. However, several studies have examined aspects, which are considered important for the evaluation of natural enemies for biocontrol. Thus Table 3 represents the „status quo" of scientific studies on biocontrol with *L. distinguendus*.

Table 1: Attractivity of samples from granary weevil infested wheat grains and from healthy grains on females of *L. distinguendus*

	F[1]	IGO	DG	HG	L
inexperienced parasitoids	** [2]	$P<0.1$	n.s.	n.s.	n.s.
experienced parasitoids	***	**	*	*	n.s.

[1]For abbreviations see text; [2] refers to statistical differences between allocation times in test- and control-fields of a 4-chamber-olfactometer: $p>0.05$ (n.s.), $p<0.05$ (*), $p<0.01$ (**), $p<0.001$ (***), Friedman ANOVA, Wilcox-Wilcoxon-test.

Table 2: Fecundity and life-span of different strains of *Lariophagus distinguendus* according to literature data and own experiments.

strain	host, conditions	fecundity[2]	life span[2,4]	reference
Leiden	*S. granarius*, wheat, 25°C	-	10±?	van den Assem, 1970
	wheat, 18°C	31-117[5](160)	-	Charnov *et al.*, 1981
Uzwil	*S. granarius*, wheat, 25°C	11±8	7±1	Steidle
Berlin		1±2	7±1	
Seoul	*S. oryzae* rice, 28°C	r_m[3]= 0.134	10±1	Chun *et al.*, 1993
	C. chinensis, beans, 28°C	r_m= 0.077	9±2	
Cairo	*St. pan.*, rice, 24°C	64±13	16±3	Kaschef, 1955
	semolina, 24°C	46±15	15±3	
	semolina (iso.ho.)[1], 24°C	164±22	27±3	

[1]isolated hosts reared on semolina; [2]mean ± s.d.; [3]intrinsic rate of natural increase; [4][d]; [5]means of different sized females (max.), (see van den Assem *et al.*, 1989).

The most important criterion is the reproductive capacity of an natural enemy, that strongly depends on the mean fecundity and on the life span (Jervis & Copland, 1996). In general the reproductive capacity of a natural enemy should be high enough to keep up with the reproductive capacity of the pest. However, as demonstrated here, fecundity and life span are not fixed but vary depending on host and host substrate, which can be explained by the fact, that hosts for oviposition and host feeding are more easy to find when isolated without substrate or in small kernels (e.g. rice) than in large kernels (e.g. beans) (Kaschef 1955, Chun *et al.* 1993). But even when reared on the same hosts and host substrate the data differ widely between strains, demonstrating different host suitabilities in different strains, which is known for other parasitoid species as well (e.g. Messing & Aliniazee, 1988). Thus the question is not if the reproductive capacity of *L. distinguendus* in general is high enough, but if the reproductive capacity of the *L. distinguendus* strain under consideration is high enough to control a certain pest on a certain substrate. Promising results were obtained from Smith (1992). He recalculated data from Gonen & Kugler (1971) on the reproductive capacity of *L. distinguendus* on *S. oryzae* reared in wheat grain, and found similar values as for *Anisopteromalus calandrae* (Howard), another parasitoid of stored product pests that is able to control the pests *Sitophilus oryzae* and *Callosobruchus chinensis* (Cline *et al.*, 1985; Press & Mullen, 1992; Wen & Brower, 1994; Wäckers, in prep.).

Table 3: Studies on *L. distinguendus* dealing with evaluation criteria for biocontrol

Criteria[1]	References
reproductive capacity (intrinsic rate of increase, fecundity, longevity)	Kaschef, 1954, 1955, 1959b, 1961; Gonen & Kugler, 1970; Charnov *et al.*, 1981; Bellows, 1985a, b; van den Assem, 1989; Chun *et al.*, 1993
Climatic adaptation (reproduction, development and mortality at different temperatures)	Hong & Ryoo 1991; Ryoo *et al.*, 1991
host selection and suitability (impact of host species,-stage and -substrate on survival, sex ratio and reproduction)	Kaschef, 1954, 1955, 1959b, 1961; van den Assem, 1971; Charnov *et al.*, 1981; Yoo & Ryoo, 1989; Chun *et al.*, 1993; Shin *et al.*, 1994
Synchronization with host (developmental time, longevity)	Gonen & Kugler, 1970; Bellows, 1985a; Chun *et al.*, 1993
Searching efficacy (host habitat location, experience, functional response, dispersal, travel speed, aggregation and walking behaviour, mutual interference)	Smirnov & Polejaeff, 1936; Kaschef, 1959a, 1964; Bellows, 1985b; Hong & Ryoo, 1991; Shin *et al.*, 1994; Ryoo *et al.*, 1996; Steidle & Schöller 1997
Synecolgy (interaction with non-hosts)	Tawfik *et al.*, 1984; Lai & Yoshida, 1992; Ryoo *et al.*, 1996

[1]adapted from van Alebeek (1996) and Kidd & Jervis (1996)

When searching for a host, the female of *L. distinguendus* has to find the habitat of the host, for instance a bulk of grain and inside the bulk the weevil infested grains. The presented results indicate, that in *L. distinguendus* this searching process is not random. As in many other parasitoid species (Vet *et al.*, 1995), females of *L. distinguendus* use volatile stimuli from both trophic levels, from the host (here: the fæces) as well as from the host plant (here: the grain) for host location. Furthermore females of *L. distinguendus* are able to learn stimuli to improve their host finding and parasitization rate (Steidle, in prep.), a fact that should be considered e.g. in inundative release measures of *L. distinguendus*. Studies in columns of wheat grain revealed, that *L. distinguendus* is able to locate granary weevil larvae hidden even 180cm deep in the grain (Steidle & Schöller, in prep.).

In summary, a lot of studies have clarified important aspects of the biology of *L. distinguendus*. Studies on reproductive capacity and on host finding indicate that *L. distinguendus* could be a promising candidate for biocontrol in stored product protection. The next task should be to test the ability of appropriate strains of *L. distinguendus* to control selected pest species under stored product conditions.

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Insect Behavior and Monitoring

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The use of pheromone traps for monitoring *Ephestia kuehniella* ZELLER (Lepidoptera: Pyralidae) and detection of parasitoids in flour mills

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ABSTRACT

The trials were carried out in four flour mills in different locations in Portugal. A study was made on the seasonal occurrence of *Ephestia kuehniella* Zeller (Lepidoptera: Pyralidae). To achieve such goal pheromone traps were used for monitoring moth populations during seven months.

The number of trap catches between treated with phosphine and untreated flour mills are discussed. The relative population levels of *E. kuehniella* collected in the traps showed differences according to the flour mill.

The pheromone traps used in untreated flour mills worked as kairomones and attracted also parasitoids of pyralids.

INTRODUCTION

The identification of the female's sex-attractant pheromone led to the development of various trap designs using these synthetic products in the detection and monitoring of *Ephestia* species (Burkholder, 1990).

Ephestia kuehniella Zeller is well-known as a pest in flour mills in temperate climates and can be considered a serious pest of cereal products and it is especially associated with wheat flour. During the day, the adult moths rest on the ceiling or walls, on shaded places of the structures and the peak periods of flight activity occur at around dusk and dawn (Bell, 1981) being particularly difficult to detect by visual observation, unless they are present in large numbers.

Development is completed at temperatures in the range of 12°C-30°C requiring 10 weeks at 25°C and 75% r.h. on white flour (Jacob & Cox, 1977). In temperate zones a larval diapause enables the species to overwinter (Cox, 1987).

In cases of heavy infestation, the larval feeding and the contamination of food material by dense silken webbing produced by the larvae, as well as cocoons, cast skins, dead bodies and frass, may be of great economic importance.

In flour mills, severe infestations affect the quantity and quality of the products, may clog the mill machinery and can cause rejection of entire lots.

In order to get information on the detection and estimate density populations of phycitine moths in factories, monitoring trials using sex pheromone baited traps were conducted in four flour mills situated in Portugal. The pheromone traps offer a new possibility to improve sampling methods, without any risks of contamination to stored products. The presence of insects in grain or milling equipment may cause fragments in flour that are aesthetically undesirable.

In recent years, several workers (Levinson & Buchelos, 1981; Süss & Trematerra, 1986; Trematerra, 1990) have successfully used pheromone traps in storage and food industry environments.

Stored-product insects are hosts to several different species of parasites, many of which eventually cause the death of the host. In untreated flour mills, the storage moth larvae are parasitized by certain wasps belonging to the families Braconidae such as *Bracon* spp. and the Ichneumoinidae, *Venturia canescens* (Gravenhorst).

MATERIAL AND METHODS

Trials were conducted in four flour mills in Portugal located in Lisbon, Alenquer, Aveiro and Santa Catarina. Two different designs of pheromone traps, delta and funnel traps, with the same pheromone lure provided by Agrisense-BCS, UK, were used for detecting and estimating stored product moth populations.

The delta trap consisted of a rigid, corrugated plastic trap with 280 mm high x 200 mm x 120 mm using a replaceable sticky insert. The sticky insert may be removed by simply opening one end of the trap and may be replaced every six weeks or when adhesive cover does not ensure effective trapping. Pheromone dispensers of the polyethylene vial type were placed in the centre of the sticky insert and should be replaced every six weeks.

The funnel trap consisted of a robust plastic trap with a hight of 230 mm and a diameter of 170 mm. It had a removable cap housing a pheromone dispenser. The moths attracted slipped into the funnel, fell into the base and were killed by DDVP. These funnel traps showed a high trapping capacity and are excellent for use in dusty environments.

Each dispenser contained 2 mg of the major component of sex pheromone (*Z,E*)-9,12-tetradecadienyl acetate. Traps were placed on structural supports and on machinery usually 2-3 m above the floor. The number of insects caught in each trap was recorded weekly in three flour mills or every two weeks in the flour mill Santa Catarina. According to manufacturer's instructions the two types of pheromone traps were positioned one per 600 m^3 and one per 2500 m^3, respectively. Traps were checked periodically for counting and removal of trapped moths.

The temperature and relative humidity in each flour mill were recorded with termohygrographs, except in the Alenquer flour mill where a termograph was used.

Lisbon flour mill

Trials were conducted in a flour mill located in Lisbon, during 24 weeks, from July to December 1994. This flour mill was fumigated with phosphine at six-week intervals, in July and August. The final products were stored from 15 to 30 days. Two delta traps and one funnel trap were placed in the first floor and in the third floor warehouses with bagged product and in the flour silos, respectively. These traps were suspended from the ceiling about 3m above the floor and renewed every six weeks. Trap captures were recorded weekly.

Alenquer flour mill

Trials were conducted, from 22 April to 7 October 1994, in a small traditional flour mill located in the outskirts of Lisbon. One delta trap was placed in the processing area covering an area of $55m^3$ and another delta trap in the packaging area with $26\ m^3$. Trap captures were recorded weekly.

Aveiro flour mill

Trials were carried out in a flour mill situated in Aveiro region, during 24 weeks, from May to October 1994. Three delta traps and two funnel traps were used. Equipment interiors such as sifters, purifiers and roll stands were cleaned in July and in August when the plant was not in operation. Trap captures were recorded weekly.

Santa Catarina flour mill

Experiments were performed in a flour mill situated in the Algarve region. Trap captures were recorded every two weeks, during 18 weeks, from June to October 1994 using two funnel traps in the processing area and in the flour silos, respectively.

RESULTS

The survey conducted in the four flour mills showed the occurrence of *E. kuehniella* within these food processing facilities.

Lisbon flour mill

In Lisbon flour mill temperatures of the third floor warehouse ranged from 27°C to 34°C from July to September and from 19°C to 26°C from October to December.

The mean temperatures of the first floor warehouse ranged between 19°C to 25°C from July to September and between 14°C and 18°C from October to December. Flour silos floor the weekly mean temperature varied between 16°C and 30°C from July to December. In the warehouses relative humidity was 53%-84% on the first floor, 44-77% on the 3rd floor and 42%-71% in the flour silos floor

Phosphine fumigation were carried out, one in the first week of August, which were partially successful and another in the end of September which revealed a rapid decrease of the number of moths caught in the pheromone traps.

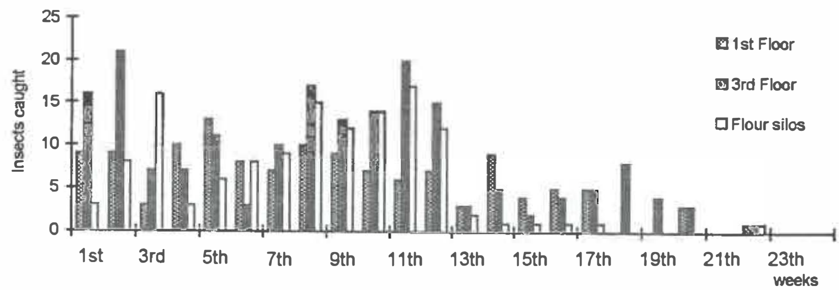

Fig. 1 - Total of males of *Ephestia kuehniella* caught in Lisbon flour mill

E. kuehniella was always present during experiments. Male moth activity was greatest in mid July (21 adults) and in mid September (20 adults), in the third floor of finished products warehouse with a total of 189 catches registered, followed by a total of 130 catches in flour silos floor, and 128 captures collected from traps of the first floor.
As this flour mill was periodically treated with phosphine the parasitoid wasps were not caught in the pheromone traps.

Alenquer flour mill

In this flour mill the mean temperatures registered varied between 15°C and 27°C.

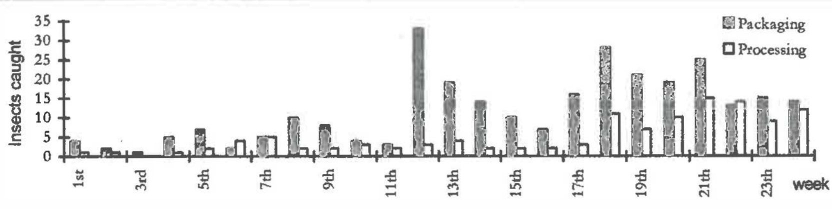

Fig. 2- Total of males of Ephestia kuehniella caught in Alenquer flour mill

The population fluctuations of *E. kuehniella* shown in Fig. 2 peaked in mid July (33 adults) in the end of August (28 adults) and mid September (25 adults) in the packing area, where a total of 285 moths catches were observed. A total of 117 males were caught in the processing area. The highest number of catches (15) was registered in mid September.

During observations three parasitoid species were identified from pheromone traps. Four adults of *Bracon brevicornis* Wesmael, 11 adults of *Anisopteromalus calandrae* (Howard) and five females of *V. canescens*.

Aveiro flour mill

The mean temperature registered during experiments ranged between 17°C and 25°C, while relative humidity varied between 57%-67% r.h.

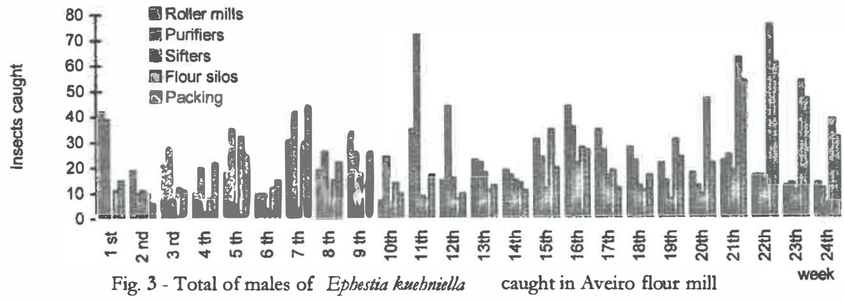

Fig. 3 - Total of males of *Ephestia kuehniella* caught in Aveiro flour mill

In Aveiro flour mill population levels of *E. kuehniella* were recorded between May and October in all the floors monitored with pheromone traps. The captures were higher in the purifier floor with 621 adults, followed by 601 catches in flour silos, 563 insects in the packing area, 548 males in the roller mills and 257 moths in the sifters. The periods of greatest activity were during July and August in the processing area and in September in flour silos and packing area. A cleaning program of the machinery were improved in the first week of July which increased the dispersion and number of moths captured (Fig.3).

Fourteen females of *V. canescens* were caught in the funnel trap placed in the packing area, during September.

Santa Catarina flour mill

The mean temperatures ranged from 21°C to 27°C and relative humidity was between 43% and 73%. In the Santa Catarina flour mill 1057 and 171 moth captures were registered in the flour silos and in the processing area, respectively.

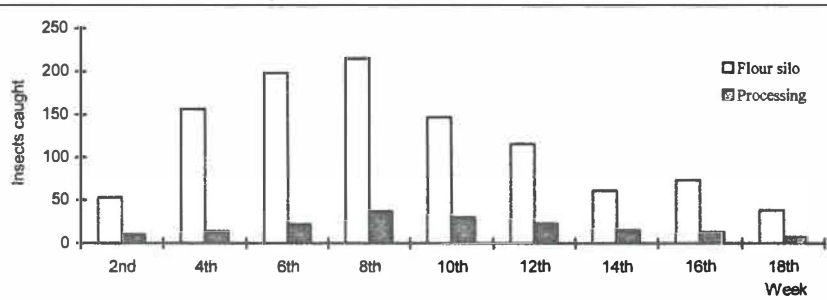

Fig. 4 - Total of males of Ephestia kuehniella caught in Santa Catarina flour mill

Adult males were more abundant in the flour silos area where the larvae were able to find considerable amounts of food. The moth populations increased through July and peaked in the first week of August when 215 moths were caught. In the processing area the highest number of *E. kuehniella* catches (37 insects) was also registered in the first week of August (Fig. 4). Totals of 122 and 20 adults of the parasitoid *V. canescens* were attracted to pheromone traps in the flour silo area and in the processing area, respectively.

CONCLUSION

During the trials the environmental conditions were favorable for moth development.

In the four flour mills the pheromone traps indicated infested areas with *E. kuehniella*, which could lead to product contamination and it has the ability to thrive in undisturbed places covered with dust and inside the machinery where light infestations can produce an increase in the population.

In the treated flour mill (Lisbon flour mill), pheromone traps were effective in detecting low *E. kuehniella* population densities while in untreated flour mills, moth captures showed relatively high population levels. Insect activity in the untreated facilities increased from mid July until September.

The pheromone traps are a very sensitive indicator of the presence of *E. kuehniella* infestations. It can be considered as alternative method to the conventional chemical control in reducing this pest populations,.

It seems that the pheromones used in traps to monitor pyralid moths may also function as kairomones and this attracted parasitoids of the pyralids.

Although with relatively slight importance in flour mills, the Ichneumonidae, especially *V. canescens* are parasitic of storage moth larvae and as such are part of the natural control complex regulating insect pest populations. *V. canescens* was recorded in the three untreated flour mills.

Among the Braconidae, *B. brevicornis* was recorded in the Alenquer flour mill, which parasitizes lepidopterous larvae (*Ephestia* spp).

Within the Pteromalidae, *Anisopteromalus calandrae* (Howard) was found occasionally in the processing area of the Alenquer flour mill. This species is of particular importance as natural enemy of stored product beetles, namely *Sitophilus* spp.

In the treated flour mill, located in Lisbon, no pyralid parasitoids could be found.

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Studies on efficacy of five types of pheromone traps for monitoring *Lasioderma serricorne* Fabricius (Coleoptera: Anobiidae) in stored tobacco

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ABSTRACT

Five different pheromone traps with or without food lure - Loline, Borgwaldt, Mini Delta, FLIT-TRAK M^2 and New Serrico - for monitoring *Lasioderma serricorne* F. (Col.: Anobiidae), were compared in two trials. The trials were carried out in a room with six horizontal silos containing stems and cut-filer of cured tobacco.
Mini Delta caught more tobacco beetles than the other four types of pheromone traps. However, from data analysis, there were no significant differences between mean catches of this type of trap and the New Serrico trap.

INTRODUCTION

Tobacco is vulnerable to many insect pests from the field to the factory. The most serious pest of stored cured tobacco is *Lasioderma serricorne* which together with *Ephestia elutella* (Hübner) (Lepidoptera: Pyralidae) can produce world-wide losses of stored tobacco of approximately 1% corresponding to about US$ 300 million (Ryan, 1995).

An integrated pest management is required to ensure a quality product without insects and to prevent losses. Control is best achieved by prevention and should include a monitoring program to know the distribution and abundance of tobacco beetles on stored tobacco. Pheromone traps may not be a mean of control themselves but effective trapping can prevent that low pest populations grow above insectistasis levels.

The present work studies the efficacy of five different pheromone traps with/without food lures to capture *L. serricorne* in a room with horizontal silos of cured tobacco where it is not possible to use any chemical control method.

MATERIALS AND METHODS

Trials were carried out in a room, of a tobacco factory situated in the outskirts of Lisbon, which presents a surface of about 1080 m^2, with six horizontal silos containing half stems and cut-filer of cured tobacco, ready to be manufactured.

The temperature and relative humidity inside this room were obtained with a termohygrograph.

Five types of pheromone traps were studied in two distinct trials. The traps were fixed in a position of 1-1,5m height according to a distance of 10m x 10m to each one to avoid trap interference and competition.

Each trial experimented three type of traps and each type trap presented five replicates, which means that a total of 15 traps per trials were studied. As the present study was to analyze a single-factor experiment it was assumed a completely randomized design which each trap was randomized weekly during six weeks. The traps were placed near windows, walls, cured tobacco and silos. Each trap was observed weekly and the insects caught were counted and identified. For data analysis, ANOVA and Duncan's Multiple Range Test were used for the comparison of treatment means,.

First trial

On the first trial three different design traps with the same lure were studied: Loline, Borgwaldt (also known as Lasiotrap) and Mini Delta traps from AgriSense- BCS, UK.

Borgwaldt and Mini Delta are triangular traps and have three exposed adhesive surfaces (each ~80mm x 150mm and ~130mm x 110mm respectively). Mini Delta presents a pattern of black and white vertical stripes. Loline trap design is made up into a slim box (~200mm x 100mm x 18mm) to protect and enclose the adhesive surface and presents also three "windows" on each side (~40mm x 20mm); *L. serricorne* enter via these open sides.

The three design traps are supplied with the same pheromone lure: (4S,6S,7S)-4,6-Dimethyl-7-hydroxynonan-3-one (Serricornin), enclosed in a small plastic vial and placed in the middle of the trap.

Each trap was changed every six weeks.

Second trial

On the second trial three different design traps and lures were studied: Mini Delta from AgriSense-BCS, UK, New Serrico from Fuji Flavor Co., Ltd., Japan, and FLIT-TRAK M^2, from Trécé of Salinas, Co., USA.

New Serrico traps are designed as a slim box (~180mm x 80mm x 7mm) to protect and enclose the two adhesive surfaces. *L. serricorne* enters via the open sides. The FLIT-TRAK M^2 is a circular pitfall trap covered from the outside with a coated paperboard to provide a printing surface and prevent curling (Muller, 1994). The pheromone lure is placed outside the paperboard and the food attractant is placed into the circular pit.

The major active pheromone component presents in these three types of traps is (4S,6S,7S)-4,6-Dimethyl-7-hydroxynonan-3-one (Serricornin).

Pheromone lures of New Serrico are prepared by covering pheromone absorbed fiber disks with polyethylene film and its attraction lasts a month.

Pheromone lures of FLIT-TRAK M^2 are enclosed in a vulcanized natural rubber dispensers. The attraction of each lure lasts from six to eight weeks.

New Serrico and FLIT-TRAK M^2 are supplied with food lures. The food lure of New Serrico is obtained by steam distillation of a few kinds of herbs in order to attract *L. serricorne* females but it is only active in the first two weeks. The food lure of FLIT-TRAK M^2 is a combination of grain and mineral oils.

Mini Delta and FLIT-TRAK M^2 traps were changed every six weeks. New Serrico traps were changed every four weeks.

RESULTS AND DISCUSSION

Temperature and relative humidity

The Table 1 reveals that, during trials, the lowest temperature of the room containing tobacco silos was 18°C (in two weeks of May and June) and the highest value, 29°C, was observed on the first week of May and on the last two weeks of July. The mean temperature were favorable (>19.5°C) for larvae development of *L. serricorne.*

The relative humidity varied between 54% r.h. (second week of July) and 70% r.h. (third week of May, first week of June and second week of July). The mean of relative humidity was also favorable for tobacco beetle development.

Table 1. Minimal, maximal and mean weekly temperatures (°C) and relative humidity (%) in the air space of the room with silos containing cured tobacco during the trials

Year: **1997**	Temperature (°C)			Relative humidity (%)		
Week	Min.	Max.	Mean	Min.	Max.	Mean
May	22	29	25.5	58	66	62.0
	18	24	21.0	55	62	58.5
	18	23	20.5	56	70	63.0
	20	25	22.5	60	68	64.0
	20	22	21.0	63	65	64.0
June	20	23	21.5	58	70	64.0
	19	22	20.5	60	65	62.5
	18	22	20.0	57	64	60.5
	19	23	21.0	57	65	61.0
July	18	21	19.5	60	65	62.5
	20	26	23.0	54	70	62.0
	20	29	24.5	57	68	62.5
	23	29	26.0	60	65	62.5

Number of *Lasioderma serricorne* trapped

First Trial

Table 2 shows that 1193 male tobacco beetles were caught during six successive weeks, on 15 adhesive pheromones traps, distributed between the following design traps: Loline traps 158 tobacco beetles, Borgwaldt traps 319 tobacco beetles and Mini Delta traps 715 tobacco beetles.

Along this trial 30 observations were made for each design trap: on Mini Delta trap 28 observations presented tobacco beetle (93.3%) and the other two type of traps *L. serricorne* was collected from 27 (90%) (Table 2).

Table 2. Total numbers of *Lasioderma serricorne* caught and frequency per design trap and per week, - first trial.

Trap Date(1997)	Loline (rep=5) Total	Freq.(%)	Borgwaldt (rep=5) Total	Freq.(%)	Mini Delta (rep=5) Total	Freq.(%)
22 May	9	100	14	60	100	100
28 May	27	80	32	100	49	80
4 June	48	80	32	100	124	100
11 June	24	100	154	80	79	80
18 June	32	100	63	100	233	100
24 June	18	80	24	100	130	100
TOTAL = 1193	**158**	**90**	**319**	**90**	**715**	**93.3**

rep= replicates; Freq.= frequency

Table 3 - Analysis of variance (ANOVA) - first trial

Source of Variation	SS	*df*	MS	F	P-value	F crit (α=0,05)	F crit (α=0,01)
Between groups	5477,62	2	2738,81	6,37	0,0026	3,1013	4,8578
Within groups	37411	87	430,01				
Total	42888,62	89					

The analysis of variance (Table 3 - ANOVA) shows that there were significant differences between groups (*F>Fcrit* for both α=0,05 and α=0,01).

Table 4 - Duncan's Multiple Range Test (s=3.78) - first trial

Traps	Loline	Borgwaldt	Mini Delta
Average	5,27	10,63	23,83
α =0,05	a	a	
α=0,01	b	b	
		c	c

same letter = no differences between means

For Duncan's test (Table 4) the standard error of each average was determined as s=3,78. The differences between means observed were different when α=0,05 or α=0,01.

For α=0,05, there were significant differences between the mean of tobacco beetle trapped by Mini Delta and the other design traps: it was the most effective design trap.

For α=0,01, Mini Delta was significant different from Loline design traps. Although Mini Delta traps trapped much more insects (average: 23,83 adults) than Borgwaldt traps (average: 10,63 adults), according the level of significance α=0,01 the differences between means of these two design traps were not significant.

From the results of this trial MiniDelta trap design was chosen to be experimented together with New Serrico and FLIT-TRAK M^2 on the second trial.

Second Trial

Immediately after the first trial finished the second trial was carried out. As Table 5 shows, within six weeks a total of 1 676 tobacco beetleswas caught. Mini Delta traps collected most *L. serricorne*, 889 adults, followed by New Serrico traps with 723 captures and FLIT-TRAK M^2 which only attracted 64 tobacco beetles.

In all the 30 observations gathered per design trap, only 18 observations of FLIT-TRAK M^2 presented adults of *L. serricorne* (60%) while in the other two types of traps, tobacco beetles were always observed (100%).

Table 5. Total *Lasioderma serricorne* caught and frequency per design trap and per week, - second trial.

Trap	FLIT-TRAK M^2 (rep=5)		New Serrico (rep=5)		Mini Delta(rep=5)	
Date	**Total**	**Freq. (%)**	**Total**	**Freq. (%)**	**Total**	**Freq. (%)**
2 July	26	40	62	100	104	100
9 July	6	60	94	100	164	100
16 July	9	60	174	100	147	100
23 July	10	60	115	100	141	100
30 July	7	80	137	100	155	100
6 August	6	60	141	100	178	100
TOTAL=1 676	**64**	**60**	**723**	**100**	**889**	**100**

rep= replicates; Freq.= frequency

Table 6 - Analysis of variance (ANOVA) - second trial

Source of Variation	SS	*df*	MS	F	P-value	F crit (α=0,05)	F crit (α=0,01)
Between groups	12694	2	6347.01	25.57	1.84E-09	3,1013	4,8578
Within groups	21595	87	248.22				
Total	34289	89					

Table 7 - Duncan's Multiple Range Test (s=2.87) - second trial

Traps	FLIT-TRAK M^2	New Serrico	Mini Delta
Average	2.13	24.10	29.63
α =0,05		c	c
α=0,01		d	d

same letter = no differences between means

Table 6 reveals that there were significant differences between groups (*F>F crit* for both). Although Mini Delta trap caught more than the other two type of traps(average: 29,63 insects), from Duncan's Multiple Range Test there were not differences between the mean of captures of Mini Delta trap and New Serrico trap (average: 24,10 insects) both for α=0.05 and for α=0.01.

The mean of catches by FLIT-TRAK M^2 was significantly lower (average: 2,13 insects) than the other type of traps studied.

CONCLUSION

From the results obtained the following can be concluded:

- The Mini Delta trap was the most effective design trap (Fig. 1). It seems that the pattern of black and white vertical stripes was very attractive to male adults of *L. serricorne*. Although, from data analysis, there were no significant differences between Mini Delta and New Serrico.
- Although New Serrico is more adequate for dusty conditions than Mini Delta, its pheromone lure lasts only a month while the Mini Delta pheromone lure can be active for at least six weeks which may render its use less expensive.
- The FLIT-TRAK M^2 trap showed the lowest level of tobacco beetles catches followed by Loline (Fig. 1).
- There were significant differences between the mean numbers of insects caught by Loline trap and the mean of the other two type of traps (Borgwaldt and Mini Delta) studied in the first trial
- There were significant differences between the mean of insects caught by FLIT-TRAK M^2 trap and the mean of the other two type of traps (New Serrico and Mini Delta) studied in the second trial.
- During the trials, the environmental conditions were favorable for the development of *L. serricorne*.

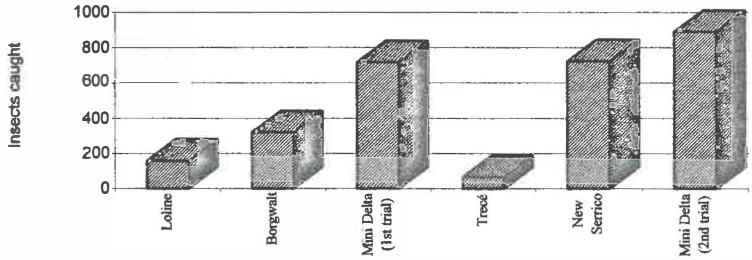

Fig. 1 - Total of adults of *Lasioderma serricorne* caught per type of trap

ACKNOWLEDGEMENTS

The author thanks Prof. António M. Mexia (CEFA Director), Prof. Pedro Amaro and Prof. St. Aubyn (ISA, Portugal) for their valuable help in the course of this research. She also thanks Mr. Enzo Casagrande from AgriSense-BCS, UK and Mr. Takao Tsuji from Fuji Flavor Co., Ltd, Japan, for receiving all the traps, needed to perform these studies, free of charge.

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Farm stored tobacco insect pests: Surveillance and population dynamics of *Ephestia elutella* and *Plodia interpunctella* moths by means of pheromone traps.

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ABSTRACT

A two-year study was carried out during 1994 and 1995 in the area of Agrinion (West-Central Greece) in order to examine the status of tobacco insect pests in the stages between harvesting and large-scale storage or processing. To that intent, traps (pheromone-baited and control ones) were placed both outdoors -where tobacco leaves were exposed to dry- and mostly inside a farm store belonging to a local tobacco producer. No insects infesting harvested tobacco were observed on open-air drying tobacco leaves. A total number of 1299 moths belonging either to *Ephestia elutella* or *Plodia interpunctella* were recorded during the trapping period. The number and sex of trapped moths was checked every other week. Data concerning the percentages of adults trapped, the sex ratios on either pheromonic or control traps are discussed and the number of generations produced by each of the aforementioned species are also estimated. Maximum and minimum temperatures recorded in weekly intervals, helped explain the two species' population fluctuation during those two years. Throughout the duration of the study, the tobacco stores were not treated with insecticides.

Key words: *Ephestia elutella*, *Plodia interpunctella*, Phycitidae, attractant traps, farm-stored tobacco

INTRODUCTION

Tobacco is cultivated all over Greece, as a highly valuable export product. Being able to thrive in soils of moderate or minimal fertility, it offers a remarkable yield per hectare ratio while at the same time it contributes significantly to the reduction of unemployment.

Harvesting begins during the first days of July in the South and about the end of July in the North, lasting approximately 1 to 1½ months. The harvested tobacco leaves are sorted out by size and degree of maturity and then they are hung in strings 2 - 3m long. Depending on variety, climatic conditions and technical means available, the drying procedure can be either sun-curing, air-curing (in the shade), fire-curing or flue-curing (using hot air).

After drying, tobacco leaves are sorted out into 3 qualitative categories. When the product reaches a suitable moisture content (10-11%), it is made up into bales and stored.

As far as tobacco in large private or state owned stores is concerned, insect pests are well known and there is a great amount of research work thereon covering biology, population dynamics and control. On the contrary, in Greece, there is no relevant data on the stages between harvesting and large scale storing (drying and farm storing).

The knowledge of insect existence, their species, as well as any damage caused by them is of particular importance to the tobacco producer, as these pests can most probably follow tobacco up to its consumption.

The present study attempts to examine and evaluate the presence of insect pests in farm stored tobacco.

MATERIALS AND METHODS

The present work was conducted in a typical tobacco producer storage facility in the area of Agrinion, West-Central Greece, which -after Macedonia- is the second most important tobacco producing district in the country. The storage room measured approx. 20 x 6 x 3.5m.

The survey lasted for 14 months (November 1, 1994 to December 31, 1995), during which period a rather invariable quantity (approx. 10t) of baled «Tsembelia» tobacco, harvested in 1994, was maintained.

The moth traps used were «Agrisense BCS» collapsible plastic Delta-traps with replaceable sticky base pad[1], either equipped with a polyethylene capsule as pheromone dispenser or left unbaited (control). Each capsule contained approx. 2mg of (Z, E)-9,12-tetradecadien-1-yl acetate (TDA) an optimal attractant source for the males of several Phycitinae species including *Ephestia elutella* (Levinson & Buchelos, 1981, Šifner & Zdárek, 1982, Buchelos & Levinson, 1985). A TDA trap was suspended in one of the corners, while a control trap was placed in the diagonally opposite corner of the store. Both kinds of traps were hung approx. 1m above the tobacco bales. TDA capsules were renewed every 45 days except for the warmer period (June - September) during which, renewal took place every 25 days. Baited and unbaited traps were rotated clockwise from one corner to the adjacent one in weekly intervals. Mean temperature was also recorded every week. The number and sex of trapped moths were checked and recorded every other week. Species identification as well as sexing was carried out by microscopy, based on the genitalia (Heinrich, 1956, Weidner, 1982). In the duration of the study the room or the tobacco were not treated with insecticides.

A number of traps, baited with either TDA or anhydroserricornin, were also suspended in places where tobacco leaves were hung in strings to dry in the shade (air-curing) in July and August of both 1994 and 1995.

RESULTS AND DISCUSSION

As shown in Table I, the highest mean temperatures inside the store were recorded in August 1994 (25,5°C) and July 1995 (26°C) while the lowest ones in February 1994 (7°C) and January 1995 (5,5°C). As the average maximum temperatures in 1994 and 1995 were lower than the corresponding outdoor ones and the average of minimal temperatures were each time higher than the corresponding outdoor ones, it is obvious that the store structure (thick stone walls and tiled roof) offers rather moderate conditions inside the room.

The mean temperatures from April 1995 up to and including December 1995 were higher than those of the respective months for 1994.

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[1] Supplied by HELLAFARM S.A., Athens, Greece

Table I. Temp. (°C) recorded inside the tobacco farm store in the area of Agrinion during 1994 & 1995.

YEAR	1994			1995		
MONTH	Minimal	Maximal	Mean	Minimal	Maximal	Mean
January	8	16	12.0	4	7	5.5
February	5	9	7.0	6	13	9.5
March	6	19	12.5	10	11	10.5
April	7	19	13.0	12	18	15.0
May	12	25	18.5	15	22	18.5
June	15	30	22.5	17	33	25.0
July	17	32	24.5	17	35	26.0
August	18	33	25.5	20	30	25.0
September	14	31	22.5	19	28	23.5
October	12	20	16.0	18	22	20.0
November	9	18	13.5	13	17	15.0
December	7	11	9.0	11	14	12.5
Average	10.8	21.9	16.3	12.1	20.8	17.2

No stored tobacco insect pests were caught by either trap, in open-air drying tobacco leaves in July and August 1994 and 1995. Bearing in mind that the quantity of stored tobacco was kept low (~10 tons) at all times, the population density of moths recorded inside the store can be considered as rather high. This effect can be attributed mainly to the absence of control measures and inadequate store cleaning.

A total of 1299 moths were trapped by both pheromone and control traps during 1994 and 1995 (557 of which in 1994 and 742 in 1995). The total of pheromone traps caught 996 moths (76,7%) while the control traps caught 303 (23,3%). The moths captured were either *E. elutella* (814) or *Plodia interpunctella* (485).

In 1994, *E. elutella* moths were flying inside the store from May up to and including November and *P. interpunctella* moths from June up to and including October. In 1995, *E. elutella* moths were flying from April up to and including December and *P. interpunctella* from May up to and including November (Fig.1 & 2).

Population density peak levels for *E. elutella* occurred in August of both 1994 and 1995 (88 and 96 moths respectively), while for *P. interpunctella* in August 1994 (65 moths) and in July and September 1995 (52 and 56 moths respectively).

In general, both species showed higher population densities between June and September. The prolonged warm periods of 1995 as compared to those of 1994, as well as longer flight periods for 1995, resulted in greater numbers of moths being recorded.

E. elutella appears earlier and enters into diapause later than *P. interpunctella*. The total *P. interpunctella* monthly numbers never surpassed those of *E. elutella*.

Assessing the relation between the flight periods observed and the temperatures recorded (Table I), one can see that *E. elutella* has exhibited increased activity at mean monthly temperatures varying between 13.5 and 25.5°C in 1994 (May to November) and between 12.5

and 26°C in 1995 (April to December). These observations are in accordance with those of Bell (1975) and Stratil & Reichmuth (1984); as to *P. interpunctella,* it seems that the insect requires rather warmer conditions in order to fly (between 16 and 25.5°C in 1994 and between 15 and 26°C in 1995) which correspond to shorter flight periods (June to October 1994 and May to November 1995).

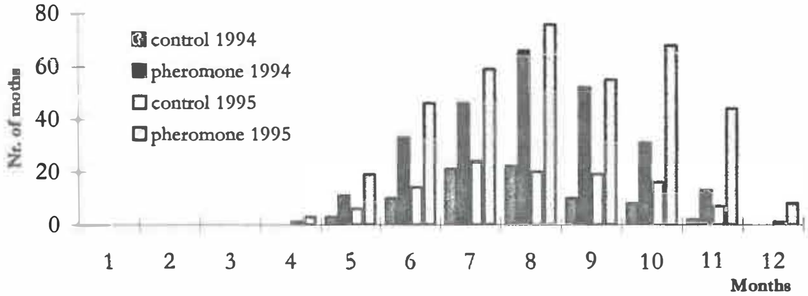

Fig. 1. Numbers of adult *E. elutella* caught per month on pheromone and control traps inside the tobacco farm store in 1994 and 1995

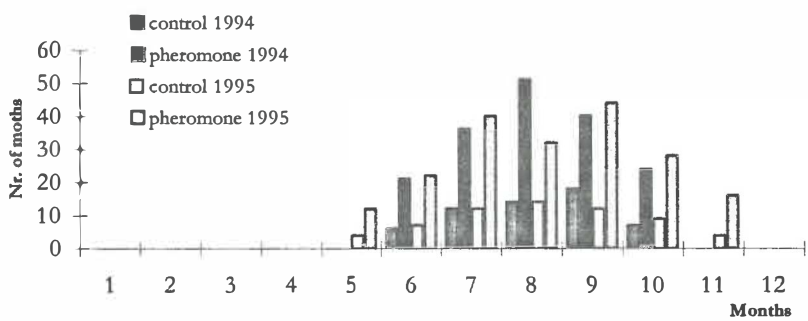

Fig. 2. Numbers of adult *P. interpunctella* caught per month on pheromone and control traps inside the tobacco farm store in 1994 & 1995

Trapped moth sexing produced the following results: 667 out of 814 *E. elutella* adults (~82%) were males and 147 (~18%) females. The males caught by pheromone traps represent ~86,5% of the total number and the females ~13,5% (~6,4 times more males than females), while the males caught by control traps represent ~77,6% of the total number and the females ~22,4% (~3,5 times more males than females).

432 out of 485 *P. interpunctella* adults (~89%) were males and 53 (~11%) females. The males caught by pheromone traps represent ~89,2% of the total number and the females ~10,8% (~8,3 times more males than females), while the males caught by control traps represent ~88,7% of the total number and the females ~11,3% (~7,8 times more males than females).

The fact that 76.7% of the total number of moths was captured by pheromone traps is certainly due to the well-known attractiveness of TDA pheromone as well as to the effectiveness of the trapping devices used. TDA, being a pheromone for male Phycitidae, attracted ~6.4 times more *E. elutella* males than females and ~8.3 times more *P. interpunctella* males than females.

The presence on control traps of more males than females belonging to both species, despite the absence of a pheromone source, can be attributed to male stored product moths usually being much more active flyers than female ones.

A thorough study of the trapping data compiled every other week (Fig. 1 & 2) as well as of the fluctuation of male and female numbers during the entire study, lead to the following conclusions on the number of generations per year for each moth:

E. elutella is likely to have at least 3 generations per year; the first one appears in early May, the second one during the last week of June and the third one -the most populated and the longer lasting- in August. In a similar survey conducted in large tobacco stores in Piraeus (Central Greece), the insect presented 4 generations per year (Buchelos & Levinson, 1985).

P. interpunctella has shown about 5 generations per year. The first one appeared in late May; the remaining 4 -definitely overlapping- are placed in mid-June, in July, in early August and early September. In the case of Greek regions of about the same latitude but in different products, such as raisin, flour etc., the insect produced 4 generations per year (Buchelos, 1980, Levinson & Buchelos 1981).

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Activity of commercial pheromone dispensers in the capture of the tobacco beetle, *Lasioderma serricorne* F. (Coleoptera, Anobiidae)

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ABSTRACT

Four different commercial pheromone dispensers effective in the trapping of *Lasioderma serricorne* F. were compared. Tests were conducted in Central Italy in a tobacco store containing Maryland and Paraguay tobacco varieties. The results show highly significant differences in the activities manifested by the different dispensers tested.

Key words: Pheromone dispensers, *Lasioderma serricorne*, tobacco store, Italy.

INTRODUCTION

Lasioderma serricorne F., a cosmopolitan and polyphagous species, is not only an important pest of stored and processed tobacco, but also of other substances (spices, flours and derivatives, plant seeds, dried fruits and flowers, dry fish, zoological collections, fabric etc.). Moreover, besides in the tobacco factories and in the food stores, recently its presence has also been reported with increased frequency in supermarkets, in dwelling houses, in libraries and in museums.

In Italy the tobacco beetle can have 3-5 generations in one year. The infestations of this beetle are controlled by chemical treatments, usually carried out with contact insecticides and with fumigant substances. The use of synthetic pheromones (serricornin or anidroserricornin) (Mochizuki et al., 1986) has allowed rationalization of the treatments to be used only in the opportune cases and in limited situations (Buchelos and Levinson, 1993; Levinson and Buchelos, 1988; Levinson and Levinson, 1987).

In the present work the results obtained comparing the activities manifested by four different commercial pheromone dispensers, available on the international market are reported.

MATERIALS AND METHODS

The studies were carried out during the year 1995 in an unheated tobacco store of about 1400 m³ (16m x 20m x 4.5m) containing tobacco of the varieties Maryland and Paraguay (in the Tobaccos Cultivation Agency of Benevento, Central Italy). Four commercial pheromones, distributed by Borgwaldt (Germany) (A), Fuji (Japan) (B), Insects Limited (United States of America) (C), and Trece (United States of America) (D) were compared (Table 1).

The activity of the various dispensers was verified in three different operative situations: comparing new dispensers; comparing dispensers 10 days old; comparing dispensers 20 days old. In the last two cases, the dispensers, before use, had previously been stored for 10 or 20 days in an environment conditioned to 25±1°C temperature (T°) with 65±5% of relative humidity (R.H.).

To reduce the influence of the trap position on the trap activity, a rotation was carried out among the blocks and among the single traps. The number of insects trapped was checked every 3-4 days, from the end of June to the end of October.

Table 1. Main characteristics of the pheromone dispensers considered

Pheromone dispenser	Trade mark	Dispenser material	Company
A	Pheromone capsule	Polyethylen vial	Borgwaldt (Gennany)
B	Serrico Lure	Table protected by polietylen	Fuji (Japan)
C	Bullet Lure	Microcapsul in polietylen vial	Insects Limited (USA)
D	CB Lures	Rubber septa	Trece (USA)

The activity of the four pheromones was evaluated by controlling the number of adults trapped in sticky traps. Lasiotrap type (produced by Borgwaldt, Germany), that have three internal sides glued. The traps were distributed at a height of 1.50 m from the floor, and arranged along the store, the traps were than grouped into three blocks, spaced 5 m one from the other.

RESULTS

In the course of the experiments the different traps captured a total of 6717 adults of *Lasioderma*, mostly males.

The flight activity curve presented a quite remarkable increase between August and early September, peaking in the first week of August with 2059 adults trapped. When the environmental parameters recorded in the warehouse (temperature and relative humidity) were put in relation with the response of the adults of *L. serricorne* to the pheromones released by the dispensers, we could observe that the catch of flying adults took place in the temperature range of 16-32°C (Figure 1).

The captures carried out by the dispensers, in the three different groups, are reported in Figures 2-7. The experimental data showed that the percentage of adults captured by the different pheromones is significantly different (Table 2) whereas the age of the pheromone appears to leave the trapping efficiency unaffected over the experimental period tested in the study (Figures 5-7).

Table 2. Activity revealed by the commercial pheromone dispensers

Pheromone dispenser	New	10 days old	20 days old	Mean
A	1089	1082	973	1048.00 ± 65.05
B	157	164	212	177.67 ± 29.94
C	762	706	742	736.67 ± 65.06
D	324	288	218	276.67 ± 53.90

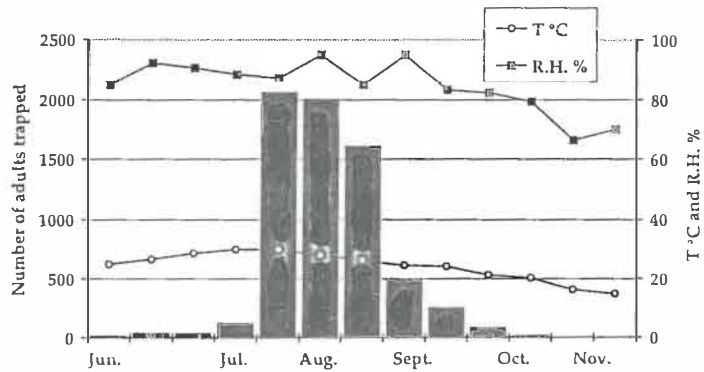
Table 3. Coefficients of correlation between the different pheromones, *t* student value for each coefficient (must be compared with $t_{a/2} = 3.106$ at a significance level of a = 0.01)

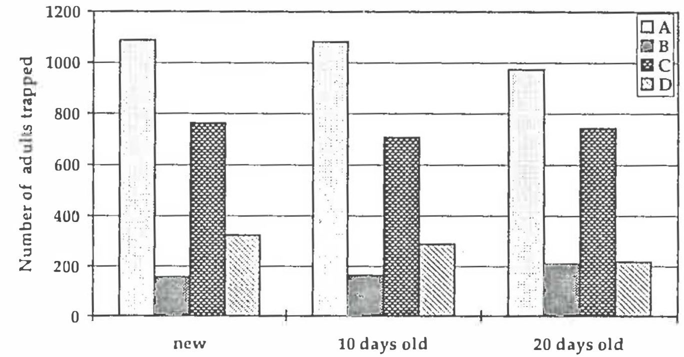
Pheromone dispenser	Coefficients of correlation (%)			*t* values		
	New	10 days old	20 days old	New	10 days old	20 days old
A → B	83.72	81.116	91.04	5.08	4.61	7.30
A → C	96.18	99.58	92.49	11.65	36.17	8.07
A → D	88.24	84.09	98.84	6.22	5.15	21.57
B → C	88.57	85.54	98.09	6.33	5.48	16.75
B → D	92.20	99.19	90.86	7.90	25.98	7.21
C → D	97.29	87.70	94.54	13.96	6.05	9.62

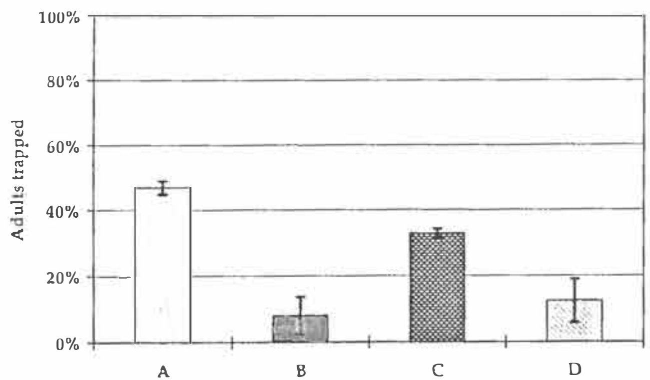
Table 4. Coefficients of correlation between the different experimental conditions for each pheromones, *t* student value for each coefficient (must be compared with $t_{a/2} = 3.106$ at a significance level of a = 0.01)

Pheromone dispenser	Coefficients of correlation (%)				*t* values			
	A	B	C	D	A	B	C	D
new → 10 days old	86.00	88.67	87.68	99.79	4.814	5.255	5.075	35.673
new → 20 days old	94.96	94.08	81.10	93.05	7.373	7.008	4.283	6.512
10 days old → 20 days old	97.04	71.09	97.02	94.36	9.716	3.705	9.680	7.169

Even though the performances of the four pheromones differ in number of captures, they have the same statistical significance in terms of flight activity detection. As shown in Table 3-4, the correlation between the captures of the pheromones, in all experimental conditions, is high.







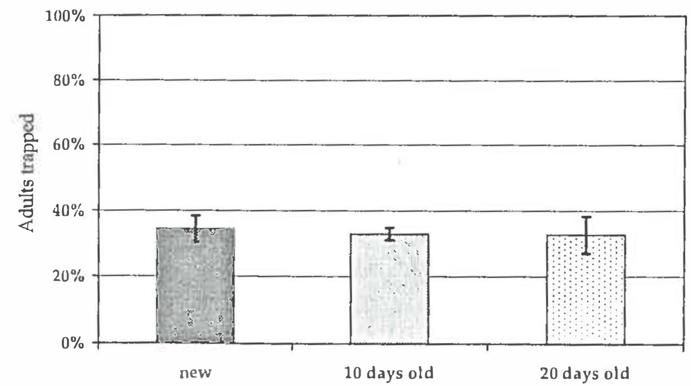
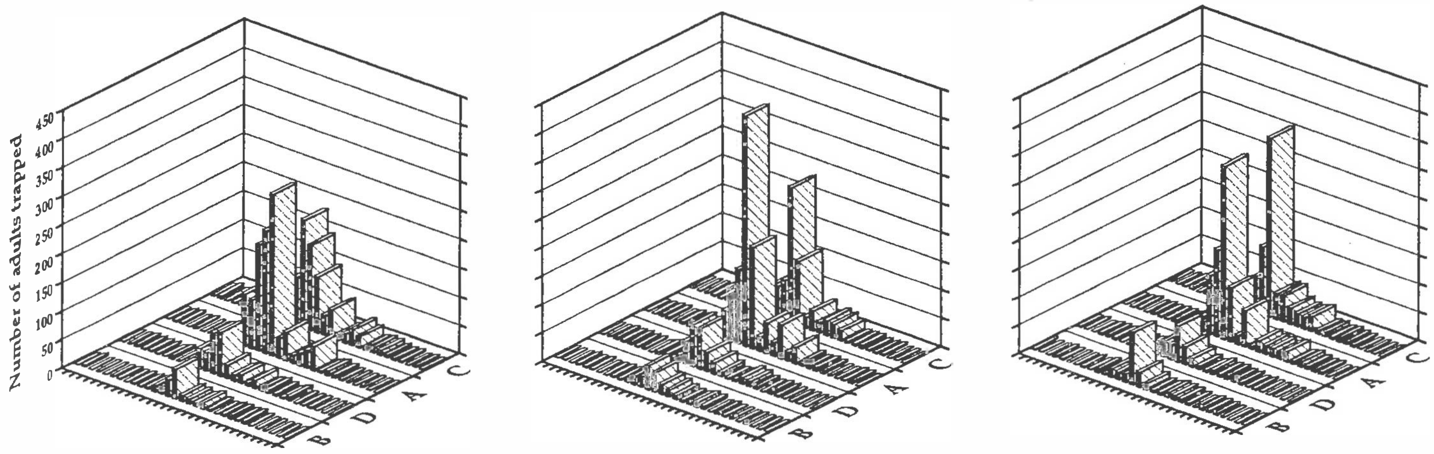


Figure 1: Total captures reflecting the flight activity of *Lasioderma serricorne* F. in the tobacco store

Figures 2-4: Captures of *Lasioderma serricorne* F. carried out by dispensers of different age and from different producers (A, B, C, D)



Figures 5-7: Flight activity of *Lasioderma serricorne* F. recorded by the dispensers: A, B, C, D New (Figure 5), 10 dats old (figure 6), 20 days old (Figure 7)

DISCUSSION

The results obtained in this study show that the commercial pheromone dispensers examined have different trapping performances. Further data in this regard, and on similar subjects, have been reported by Carvalho and Amaro (1995) and by Gèneve et al. (1995). Nevertheless, the various dispensers - under different conditions - had been able to monitor the presence of the adults of *L. serricorne* in the warehouse and the development of the infestation.

The trapping activity of the pheromone dispensers **A** and **C**, compared to that manifested by **D** and **B**, could be related with the different releasing capacity of the pheromone and with the degree of purity of the chemical compounds.

The release of pheromone is strongly conditioned, amongst other things, by the baited dose, by the stabilizing compounds used and by the material of the dispenser. The purity of the attractive compound employed on the other hand depends on the chemical synthesis used for the extraction of the active substance that, in the different cases, involves differentiated times and costs. Moreover, from a practical view-point, the activity of each dispenser is influenced as well by the trap in which it is placed (for example color, shape, sticky surface, etc.) and on other environmental factors, such as brightness, temperature, airflow, trap position, infestation rate, etc.

In the optimization of the Integrated Pest Management of the tobacco beetle, but also of other pest insects, it is useful to take into consideration the different activities revealed by the commercial pheromones.

In order to assure a continuos supply of lures of comparable quality and to allow comparison between lures of different origin, Arn et al. (1997) proposed to adopt the procedure of batch certification.

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Storage Techniques and Other Pest Control Methods

Integrated Protection of Stored Products
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Instinctive grain storage habitually performed by certain animal species

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Man has occasionally declared himself as the inventor of grain storage, which should render food and seed supplies continuously available throughout the year. It seems, however, that *Homo sapiens* has merely copied the inborn behavior patterns of certain seed- and fruit-gathering species of ants, rodents and birds.

Underground seed storage performed by granivorous ant species including *Messor barbarus* and *Pheidole providens* (Formicidae), as well as cereal storage by some species of squirrels (Sciuridae), hamsters, rats and mice (Cricetidae), especially the Syrian hamster *Mesocricetus auratus*, are rather familiar examples, while seed-storing bird species are perhaps less known.

Some omnivorous crows, jays and magpies (Corvidae) as well as tits (Paridae) have a marked instinct of storing seeds in bark crevices, below lichens and among pine needles of trees, in order to overcome periods of food scarcity. The acorn woodpecker *Melanerpes formicivorus* (Picidae) is feeding on insects and seeds, among which the latter are stored in huge numbers (Fig. 1). These birds are known to drill numerous holes of varying size in the bark of trees and sometimes in wooden posts, whereupon they tightly push acorns (*Quercus* spp.), other seeds and even smooth pebbles resembling the shape of the bird's beak into cavities of suitable size. The woodpecker first inserts the narrow tip of the acorns into the cavities, while the flat base of the former is facing the bird's beak. Acorns being tightly immersed to such artificial cavities are safe from pilferage by other animals. Moreover, seeds stored in "tree granaries" may be fairly well protected against infestation by microorganisms and arthropods due to secondary metabolites produced by the tree's cambium.

In a Californian forest, ~ 50.000 acorns were found inserted in a singly yellow pine and ~ 20.000 acorns were found embedded in an old sycamore tree (Ritter, 1929, 1938). The woodpeckers usually return to their self-made "tree granaries", when the seed supply of the acorn trees in the forest is exhausted.

In antiquity, the seed-storing habit of the above animals was praised to mankind as a worthwhile manner of existence. A famous parable ascribed to the Greek author Aisopos (6^{th} century BC) intends to save mankind from an easy-going and futile life like "that of the cicada" and recommends instead of this to adopt the ant's way of life: "Store seeds for the future, when ever you can, and never mind entertaining the travelers".

We would like to supplement this concept by expressing our gratitude to the granivorous ants, cricetid rodents, woodpeckers and all other seed-storing animals for the invaluable lesson they

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* In commemoration of the fifth anniversary of the IOBC/wprs study group on Integrated protection of stored foodstuffs and other commodities, founded by Prof. Dr. Giorgio Domenichini on 23.9.1992 in Piacenza

have taught mankind, particularly the hunters and gatherers of the neolithic period (~ 5000 - 3200 BC).

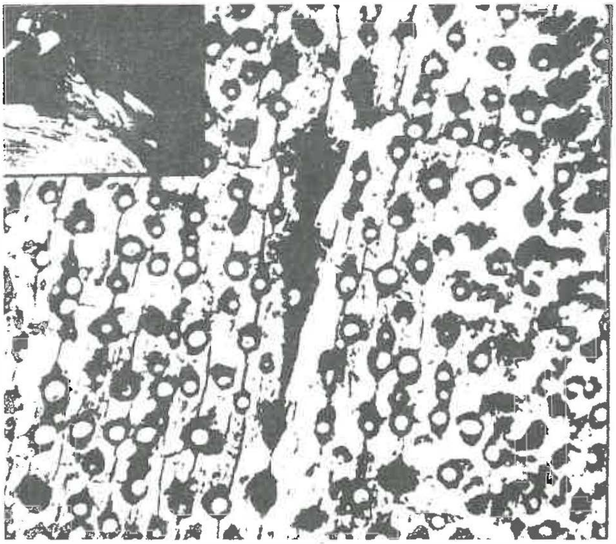

Fig. 1 Partial view of a "tree granary" produced by acorn woodpeckers in a Californian forest (Koenig & Mumme, 1987). The cooperatively breeding *Melanerpes formicivorus* (Picidae) is shown in the upper left corner of the figure.

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Traditional rice storage in southern Guinea-Bissau: Potentials, limitations and possible improvement on local methods

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ABSTRACT

Guinea-Bissau is a West African country where rice is the main staple. Self-sufficiency in cereals has been, since colonial times, the main priority of the government. However, no planned intervention has been undertaken to reduce post-harvest losses at the household level. Field research was conducted in the south of the country, the heart of rice production. Empirical data revealed considerable post-harvest losses.

In this paper we describe the indigenous storage management of mangrove swamp rice and the main sources of storage losses for each of the ethnic groups living in the region. Finally, we propose a framework design for a participatory ethnographic and agro-ecological approach to further study and improve traditional post-harvest management of rice in Guinea-Bissau by the introduction of an appropriate integrated pest management programme.

Key words: Africa, Guinea-Bissau, mangrove swamp rice, local knowledge, traditional storage facilities, traditional rice storage management, participatory methodologies of R&D, IPM.

INTRODUCTION

Guinea-Bissau is a small country, with approximately one million inhabitants and an area of 36000 km². To the north lies Senegal, to the east and south, Guinea, and to the west, the Atlantic Ocean. Although a small country, Guinea-Bissau has a great agro-ecological and ethnic diversity, which is reflected in both production and storage systems. The climate is characterized by two distinct seasons - a rainy and a dry season -, classified as Aw[3] by Köppen (Abreu and Correia, 1993). The rainy season lasts about five months, starting in May and precipitation can rise above 2750 mm in the southern region.

The traditional social structure was only superficially changed by the colonial government in some regions of the country. The activities of production, storage management, distribution and processing are still organized at the level of the extended family compound, called 'morança' in the Creole language of Guinea-Bissau. Schiefer and Havik (*in* Oliveira *et al.*, 1996:22) state that the 'morança' «is not just a residential unit, but also a household in itself in the broad sense of the term, i.e., the centre of a network linking the economic aspects of production, distribution and processing, to the socio-political (lineage, clan, gender, age) and

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[3] Tropical rainy climate with a distinct dry season and a mean monthly precipitation inferior or equal to 60 mm during one month.

cosmological spheres of these societies». Marriage is polyginous and in the same 'morança' can exist several basic units of transformation and consumption ('fogão').

The large rural sector relies primarily on subsistence activities such as agriculture, gathering, fishing and hunting. For this reason, in this paper we use the broader word «rural producer» instead of «peasant».

The country falls within the mangrove swamp rice belt of Africa, making this cereal the main staple. Traditional rice varieties include *Oryza sativa* and *Oryza glaberrima* species (Schwarz, 1993).

After independence, in 1974, the main priority for agricultural research and development in Guinea-Bissau has been the attainment of self-sufficiency in rice production.

The Department of Agricultural Research (DEPA), established in 1978 within the Ministry of Rural Development and Agriculture (MDRA), was responsible for all research on rice. DEPA's Caboxanque Centre - which was situated in the Cubucaré region - concentrated its activity on selecting improved mangrove rice varieties, through both station and on-farm research. It is important to note that high yielding varieties are often more susceptible to storage attack than traditional ones (Compton *et al.*, 1993; Wright, 1995).

However, these selected varieties were rejected by producers after a brief period of experimentation, because some basic criteria used by the agrarian societies when selecting rice varieties were not taken into account by researchers (Temudo, 1996). At the same time, the rehabilitation of rice polders ('bolanhas salgadas') partly abandoned or destroyed during the liberation war, counted among the most important agricultural development projects. About this effort, Kohnert (1988:171) states that «in view of the inadequacy or complete absence of social feasibility studies and the lack of involvement of the peasants in the projects, their rate of acceptance has been disappointingly low».

For these reasons and also some ecological problems but mainly because of a inadequate price and market policy, self-sufficiency in rice production has still not been reached after twenty years of post-independence planned intervention.

At the household level, most producers face a cyclical shortage of cereals from the last months of the dry season to the first harvest. This could be at least shortened in length and intensity through pre- and post-harvest reduction of losses. Though post-harvest losses are a key problem in food security, all development interventions at the household level have had a production-oriented approach through the introduction of high yield varieties and other external inputs like fertilizers and pesticides. This approach has been firmly criticized by some authors like Sigrist (*in* Oliveira *et al.*, 1996) and Schiefer and Havik (*in* Oliveira *et al.*, 1996). Compton *et al.* (1993:284) maintain that «in the tropics, 60-80% of all grain produced is said to be stored at farm or village level, although this figure conceals important national and crop-based differences». Until now, only one comprehensive study (Oliveira *et al.*, 1996) has been undertaken of household storage systems in Guinea-Bissau, specifically of five of the main ethnic groups: Balanta, Beafada, Fula, Mandinga and Nalu.

Field research was conducted by the first author in the south of Guinea-Bissau, on the Cubucaré peninsula situated in the region of Tombali, from November 1993 to July 1996.

This research is part of a larger study by the same author on knowledge and institutional interfaces in the development of new technologies in subsistence agriculture.

Research methodology included participant observation, participatory rapid appraisal techniques and open ended interviews. Respondents consisted of household heads ('chefe de moranças') and their wives from the main ethnic groups that produce mangrove swamp rice in the region: Balanta, Nalu, Sosso, Djacanca.

Open ended interviews included the families of 47 'moranças', situated in 26 villages scattered over the Cubucaré region.

Although major losses occur also at the pre-storage stage and many storage problems are due to previous management, in this paper we will only deal with the losses which occur during rice storage.

Indigenous storage management of rice

In the south of Guinea-Bissau, storage reflects specifically the way in which production is organized and in general the very social organization of the communities. Although storage is organized within the 'morança', collective productions are stored under the supervision of their head, or someone appointed by him, while individual productions are kept by each of their owners. Storage facilities and methods also reflect these two levels on which storage is organized: collective productions have, in general, their own storage structures and are subjected to special care that tries to minimize pest attack. In contrast, individual productions are stored in the sleeping rooms of their owners in bags, baskets or even wrapped up in pieces of cloth, becoming an easy target for rodents.

Contrary to what happens to the traditional production activity, storage management is not submitted to a continuous process of experimentation and selection. Changes have been restricted to the adoption of storage facilities that reduce labor needs.

Mangrove swamp rice is always stored after being threshed following several months of sun drying in a heap in open air.

The storage is done in a variety of granaries and containers depending on the ethnic group, but also according to whether it is paddy or husked rice and also whether seeds or rice are kept for consumption, sell, barter or gift.

Certain ethnic groups favor special storage types which can be specific of them: only Balanta have mud brick granaries and granary compartments; all the other ethnic groups prefer mud brick 'niches' and store rooms; amphora shaped mud silos are used both by Balanta and Djacanca ethnic groups.

Other social factors, like the potential occurrence of robberies, contribute to the choice of some storage structures and the abandonment of others.

In granaries and granary compartments, paddy for home consumption is stored in bulk. Seeds of the different varieties can be kept separately in polypropylene bags laid on top of the bulk rice. These granaries are circular mud brick houses roofed with straw, with only one little entrance at the top of the wall. Granary compartments are divisions of the houses with no door and only one entrance at the top of one of the four walls.

All these open granaries have the big disadvantage of allowing pests and atmospheric moisture to enter the outer layers of the grain, leading to large losses.

The other ethnic groups also have another type of open granary which is a kind of square shaped niche constructed of mud bricks in the corner of sleeping rooms or store rooms and with a maximum height of a man. Paddy is also stored in bulk inside them.

Store rooms[4] are increasingly being used by all ethnic groups other than the Balanta. These are ordinary rooms where a variety of products are stored inside different types of containers: polypropylene bags, baskets, metal drums (200 l volume). When needed they can easily be converted into sleeping rooms. However, contrary to the majority of ordinary rooms they have a door with a lock in order to permit control over the collective stored products. Their floor is sometimes coated with cement, which substitutes the traditional mud made from termite nests. Rice stored inside this kind of space is most frequently kept in polypropylene bags, which sometimes are placed in direct contact with the floor and the walls and even when they rest on a wooden rack ('bentém'), they are not placed in such a way as to reduce pest attack.

Balanta and Djacanca ethnic groups frequently store seeds in a kind of amphora shaped mud silo of different sizes. When big (up to 500 kg), they can also store consumption rice and seeds which are kept inside bags. These silos are hermetic containers, sealed with mud, and can be placed inside a room, in the verandah or outside the house. In this last case, they are covered with a wooden structure roofed with straw.

Husked rice is stored in polypropylene bags and metal containers placed inside the house.

In the region under study many traditional methods of pest control are still practiced or at least known. Knowledge in traditional methods of reducing post-harvest losses are ethnic and gender determined.

At the extended family compound level, there is a social differentiation of knowledge and responsibilities. Men usually construct the collective storage structures, but women are the ones responsible for all the post-harvest management.

De Lima (1994:918), mentioning socio-economic studies performed in Asia, Africa and South and Central America, states that «women determine the rate of consumption, pest control activities and other measures to prevent food losses». The research conducted in Guinea-Bissau also confirms these conclusions.

Using Parrish's (1994) classification, we divide the traditional methods of pest control, in the south of Guinea-Bissau, into three types:

a) chemical: use of sealed containers, *Capsicum* spp. fruits and seeds, *Cassia sieberiana L.* leaves and chemical pesticides;

b) mechanical: use of salt, metal traps, platforms on granaries and legs (such as stones or mud bricks) on other containers;

c) biological: use of cats, sun drying and parboiling.

However, in the region of Guinea-Bissau under study producers also perform a variety of magic-religious ceremonies to protect crops and stored products against theft, pests, sorcery and even against too rapid consumption. Stored products may also be protected with two kinds of magic objects called in Creole 'guardas' and 'manjiduras'.

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4 Compton *et al.* (1993) illustrate the advantages and disadvantages of using this type of storage.

No annual sanitary measures are practiced to prevent infestations of the granaries and containers. Compton *et al.* (1993:287) state, however, that storage losses due to the attack of insects and rodents «can potentially be reduced by simple hygiene measures».

The use of mud silos and metal containers sealed with rice straw and mud can be considered within the chemical measures given the fact that they act as rudimentary fumigation chambers, because rice grains continue to give off carbon dioxide (Parrish, 1994). However, the mud silo construction skills are not being passed on to the younger generation and this knowledge will soon be lost.

Metal containers could be a good alternative, but they are extremely expensive for these resource poor producers. They are furthermore used in a multifunctional manner: at the time they are new, they are used for palm oil processing and storage and only when they have holes do they begin to be used for grain and peanut storage.

Against rodents most producers have cats at home, they also use chemical rodenticides and mechanical traps.

Before the beginning of the rainy season stored rice is usually completely husked or parboiled in order to free women for field agricultural work. Previous to husking, rice is sun dried on the ground or on a mat. As Parrish (1994) says, sun drying activates the life cycle of insects that have infested the grain and some of them will complete it before storage. However, this method also reduces the moisture content of the grain making it less susceptible to the infestation of insects and moulds.

In the storage of husked rice, salt and capsicum[5] seeds and fruits are traditionally used to reduce insect losses. The leaves of *Cassia sieberiana* ('canafistra') are also used by a reduced number of Balanta women as a similar defense against insects during storage[6].

The quantities used of all the products mentioned above were not specified and are supposed to vary significantly from woman to woman.

Parboiling is practiced by all ethnic groups except Balanta before storing paddy to be consumed during the rainy season. The main reasons noted for using this treatment are to reduce both the period of rice shortage (by the increase of grain volume) and insect attack during storage. It also reduces the difficulty of manual husking and allows this operation to be done bit by bit during the rainy season. However, producers state that parboiling destroys rice taste and its nutritional value.

DEPA tried to introduce commercial pesticides for stored rice seeds. After this governmental department was closed, the producers' supply of pesticides was kept up by ex-DEPA extension agents and by retail traveling salespeople ('djilas') from Guinea.

Compton *et al.* (1993:301) summarize the main problems found in the use of commercial insecticides in developing countries, which are also faced by Guinea-Bissau producers: «storage insecticides can travel a long and tortuous route from the factory to the farmer, and farmers may have difficulties in obtaining the correct chemical formulation at the right time

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5 This method is still being studied, but is considered a good protection against rice pests during several months (GTZ, 1995).

6 Gomes (1993) studied the properties of the root of this plant used in traditional medicine in Guinea-Bissau, and concluded that it has tannins, anthraquinones and flavonoids with antibiotic activity.

and in an appropriate pack and size (...), misuse of commercial insecticides by farmers is a common problem».

In the region under study, producers do not have any method to evaluate storage losses. Only losses in husked rice attributed to insects are perceived by producers as being big. Probably, the main reasons for this are: firstly, almost all the rice for home consumption/gift/barter is stored in bulk after threshing, in large granary compartments, granaries or 'niches' which make it difficult to assess losses; secondly, no calculation of the potential period of consumption is done for cultural reasons[7].

Wright (1995:173) points out that other authors «maintain that farmers are usually less aware of post-harvest problems and losses than other participants in the food distribution chain, but this assertion is not substantiated and no attention is given to the possibility that differences in awareness may reflect differences in toleration of losses».

Main sources of rice storage losses

Rodents and insects are considered the principal causes of loss during storage. Producers perceive losses caused by insects after rice is husked as the largest occurring during storage.

Carvalho (1984) identified several rice insect pests: *Cryptolestes turcicus* Grouvelle, *Palorus (Circonus) subdepressus* (Wollaston), T*ribolium castaneum* (Herbst), *Tribolium confusum* (Duval), *Ephestia cautella* (Walker). However, this author did not indicate which grain sampling methods were adopted, what type of storage nor how the rice was stored (unthreshed/paddy/husked).

Frazão and Evaristo (1993) also cited some storage insect pests in Guinea-Bissau products, some of which can infest rice: *Sitophilus oryzae* (L.), *Rhizopertha dominica* (Fab.), *Tribolium confusum* J. du Val, *Oryzaephilus surinamensis* (L.), *Sitotroga cerealella* (Olivier).

In paddy stored in open granaries ('niches', granary compartments and granaries) termites can sometimes cause considerable losses.

Moulds are not considered important, but producers are conscious that they must dry the grain correctly and elevate the bottom of the granaries and containers from the floor - which becomes wet during the rainy season - with platforms, stones or bricks in order to avoid such attacks.

During the sun drying of paddy, domestic animals are thought to be an important threat. Therefore, a child is charged with vigilance of the produce.

When the rice is stored inside the houses or in the verandahs, fire is a powerful enemy as the houses are roofed with straw. Because of that Balanta producers always protect their belongings and stored crops by making a ceiling with mud bricks.

Producers frequently accuse their wives of stealing the collective rice of the family. Because of this, generally only one person is authorized to enter in the granary to take rice for daily consumption.

In contrast, amongst the Balanta some men are accused of stealing the collective rice to buy alcoholic drinks. When that happens, their wives forbid them to enter the granary and appoint one of their sons to the task.

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7 Rural producers believe that if they calculate the time during which they will consume their harvest and they discover that it is just or not enough for the whole year, then they would be afraid of offering rice to relatives and friends.

CONCLUSIONS AND IMPLICATIONS FOR DEVELOPMENT

Compton *et al.* (1993:285) call attention to the fact that although most traditional storage systems are well suited to their farm circumstances, generating low losses, «several factors have increased the scale of losses over the past two decades, including: the increased cultivation and storage by small farmers of high-yielding varieties (HYVs) with poor storability; the decreasing availability of important storage inputs such as construction materials, fuelwood and botanical pesticides; and in Africa, the advent of a new storage pest (the larger grain borer)».

The research conducted in the south of Guinea-Bissau revealed that:

- post-harvest management is the heart of household food security in an agricultural subsistence based economy;
- household socio-economic organization of post-harvest management is a central question in any intervention process[8];
- post-harvest management is also a ritualized process in these agrarian societies and this must be taken into account in an appropriate process of technology development;
- producers do not have any method to quantify post-harvest losses;
- producers' subjective assessment of post-harvest losses prevent them from improving the existing post-harvest management techniques, granaries and storage containers. Although they perceive pre-harvest losses as high, they under-estimate losses occurring after harvest with the exception of husked rice;
- labor shortage and other socio-economic factors are encouraging the abandonment of some traditional types of granaries and silos as well as pest control methods and consequently resulting in a collective loss of post-harvest management knowledge and skills;
- traditional post-harvest management of rice can be easily improved, given the relative wealth of the local knowledge and the results of recent research (Compton *et al.*, 1993; GTZ, 1995; Hall, 1971; GTZ, 1980);
- rural producers perceive labor shortages as one of the most limiting factors affecting their decision to adopt improved technologies;
- neem (*Azadirachta indica*) was introduced in Guinea-Bissau and still exists in the region of Tombali. It is also possible to find other plants, like *Khaya senegalensis* and *Annona reticulata* known for their properties of reducing storage losses (GTZ, 1995).

It should also be considered that:

- agricultural research measures need to be not only technically feasible, but also economically and socio-culturally acceptable to rural producers. Building on producers' existing practices and knowledge systems helps researchers, particularly in resource poor countries like Guinea-Bissau, to focus on finding solutions to producer-driven problems (Chambers *et al.*, 1983; Richards, 1985; Chambers *et al.*, 1989; Dupré, 1991);

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[8] Our findings corroborate the reaserch conducted in Guinea-Bissau by Oliveira *et al.* (1993).

- one of the most commonly mentioned problems associated with low agricultural output and low adoption of improved agricultural technologies in developing countries is the lack of producers' involvement in the research and extension processes (Box, 1988; Compton *et al.*, 1993; Scoones and Thompson, 1994; Wright, 1995[9]);
- producers' perception of the characteristics of agricultural technologies and the need to change the prevailing ones strongly influence their adoption behaviour[10];
- the chemical approach to reducing post-harvest losses causes health and environmental problems and is not appropriate for resource-poor producers, particularly where they are illiterate (and cannot read users instructions of commercial pesticides), markets are unstable, supply is irregular and extension services are non-existent or low in performance;.
- general concern for environmental protection and resource economy encourages the study of non-chemical methods of storage pest control. However, there is a need to clarify the efficiency of traditional methods, study the possible toxic residues left in stored products by natural pesticides and the possibly different concentration level of active compounds in the composition of plant pesticides all through the year and from one region to another and consequently the quantities necessary for attaining efficacy (GTZ, 1995).

For all these reasons, we propose a framework design for a participatory ethnographic agro-ecological approach to study and improve traditional systems of rice post-harvest management in Guinea-Bissau. This would include:

a) study of the socio-economic organization of crop production and storage in all ethnic groups;

b) study of all the post-harvest management methods used with rice;

c) study of the traditional methods of post-harvest reduction of losses and their efficiency evaluation;

d) study of the pest resistance characteristics of the different rice varieties in production;

e) study of the producers' perception of post-harvest losses;

f) assessment of post-harvest losses with the full participation of local producers;

g) identification of rice storage pests and study of their biological cycles;

h) identification and quantification of the active compounds of the natural products used in traditional post-harvest reduction of losses;

i) assessment of the possible toxic residues left in the rice by the natural products used in pest control;

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[9] Wright (1995:172) states that «loss studies are almost without exception undertaken without any consultation of the farmers' need for the work or their views on losses. Except for purely academic purposes, there is little value in measuring losses to which the keeper of the grain attaches no importance».

[10] Wright (1995:173) mentions that «If the reason for loss studies is to reduce losses through some form of change, then it follows that those changes will take place only if the persons concerned perceive that loss as important. That perception will differ according to circumstances».

j) out of the confrontation between rural producers' perception of losses and real losses, try to obtain the full participation of rural producers for:

- the introduction of improvements in traditional storage facilities;
- the introduction of appropriate IPM measures with large scale diffusion of the post-harvest traditional methods found to be efficient.

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Efficacy of diatomaceous earth against stored product pest insects

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ABSTRACT

The diatomaceous earth (DE) Dryacide® was tested under laboratory conditions on surfaces (2g DE/m²) and in wheat grain (0,3 % by weight) at 70±5% R.H. and 22±1°C. The effect of surface treatments was tested on adults and larvae of *Ephestia kuehniella*, *Oryzaephilus surinamensis*, *Tenebrio molitor* and *Tribolium castaneum*. The efficacy of grain treatments was determined using adults and larvae of *Ephestia elutella*, *O. surinamensis*, and *Tribolium confusum* as well as adults of *Sitophilus granarius*. A second DE, TEM 333®, was tested as grain treatment against the adults of *S. granarius* (1, 2, 4 and 8 %; moisture content: 14%; 22±2°C; 70±5% R.H.).

100% mortality were reached with the surface treatments in adults and larvae of *O. surinamensis*, as well as the adults of *T. molitor* and *E. kuehniella* after an exposition time of 3–9 days. Against *T. castaneum* and the larvae *E. kuehniella* no complete control could be achieved. The surface treatment had no effect on the larvae of *T. molitor*.

In the grain treatments the dosage of 0.3 % Dryacide® reached 100% mortality in all tested pests except *S. granarius*. Most sensitive were *O. surinamensis* and *E. elutella*. In *T. confusum* the adults died within 13 days of treatment, but for complete control of the larvae 13 weeks were necessary. Against *S. granarius* the silica dust showed no satisfactory efficacy, 49 days after treatment adult progeny was observed. TEM 333®, as well, could not control *S. granarius* under the tested conditions. 32 days after treatment 37–62 % of the beetles survived and after 12 weeks progeny was found in all treated samples.

INTRODUCTION

Stored product protection is needed since people started to store products, especially grain and other seeds. Earth from the fields and ashes are reported to be among the most important protectants for grain in ancient Egypt some 5000 years ago (Hoffmann, 1964). The beginning of our century witnessed a revival in interest in inert dusts. In Germany, *Franz Zacher* recommended diatomaceous earth, stone meal and other surface-active powders against the granary weevil (Weidner, 1983).

Recent studies of different DE confirm the efficacy of different preparations for stored product protection (Aldryhim 1993; Desmarchelier et. al. 1994, Grahn 1995). These findings have promted a more wide-spread interest in amorphous silica dusts within the scope of ecologically safe pest control.

The present examinations were carried out to determine the efficacy of the silica-dusts Dryacide® and TEM 333® against stored product pest under the Central European climate – at a relative humidity of 70±5% and a grain moisture content of of 14–14,5%.

MATERIALS UND METHODS

Surface treatment:

Three tests with 3 repetitions and one untreated control were made for a period of 9 or 15 days at a relative humidity of 70±5% and a temperature of 22±1°C. Test insects were adults and larvae of the following typical pests of flourmills : *E. kuehniella*, *O. surinamensis*, *T. molitor* and *T. castaneum*. Per stage 30 individuals were tested (without substrate). Plywood plates were treated with Dryacide® in a concentration of 2 g/m². The insects were placed onto the plates in tephlon coated glass rings (diameter: 50mm, height: 40mm) with gauze lids. In the third test the application technique was changed. In order to improve the even distribution of the dust it was passed through a 1mm wide sieve.

Wheat grain treatment:

Tests with Dryacide® and TEM 333® were carried out at 22±1°C on adults and larvae of *Ephestia elutella*, *O. surinamensis*, and *Tribolium confusum* as well as adults of *Sitophilus granarius*. A mixture of 48,5g wheat grain and 1,5g wheat bran (in tests with *S. granarius* just 50g of wheat grain; moisture content 14 – 14,5%) were mixed with 0,15g Dryacide® corresponding to a concentration of 0,3%. Per species and stage 30 test insects were introduced. Insects were checked for mortality 1 day, 5 and 6 days after treatment and thereafter in weekly intervals.

In a second test 500g of wheat grain were mixed with 5g, 10g, 20g or 40g TEM 333® corresponding to a concentration of 1%, 2%, 4% and 8 %. 100 recently hatched grain weevils were added. Mortality was checked on the 32nd day and 12 weeks after treatment.

RESULTS

Surface treatment

Results of the surface treatments with DE Dryacide® are shown in table 1. A complete control of the insects was only reached in the adults and larvae of *O. surinamensis*. On the 7th day after treatment all adults of *E. kuehniella* were dead, but one day later all insects in the control were also dead. In comparison with the first and second test the third test reached a better efficacy of the DE against the pest insects. 100% mortality were achieved in the adults and larvae of *O. surinamensis* as well as the adults of *T. molitor* and *E. kuehniella*. However, adults and larvae of *T. castaneum* and the larvae of *T. molitor* and *E. kuehniella* could not be controlled.

Wheat grain treatment:

In table 2 all results of the treatment of grain with Dryacide® are given.

Table 1: Average mortality of adults and larvae after surface treatments with 2 g Dryacide®/m² (22±1°C, 70±5% R.H.)

Insects/stages		Average mortality in % (in brackets: time of mortality)		
		1. test (15 d)	2. test (9 d)	3. test (15 d)
O. s.:*	Adults	100 (15th day)	66,7 (9th day)	100 (7th day)
	Larvae	-	100 (8th day)	100 (7th day)
T. c.:*	Adults	66,7 (15th day)	6,7 (9th day)	64,4 (15th day)
	Larvae	60 (15th day)	53,3 (9th day)	58,5 (15th day)
T. m.:*	Adults	44,4 (15th day)	22,2 (9th day)	100 (9th day)
	Larvae	0 (15th day)	0 (9th day)	0 (15th day)
E. k.:*	Adults	100 (7th day)	93,3 (9th day)	100 (3rd day)
	Larvae	85,2 (15th day)	-	76,7 (15th day)

**O. s. = O. surinamensis; T. c. = T. castaneum; T. m. = T. molitor; E. k. = E. kuehniella*

Table 2: Time of 100% mortality of adults and larvae after grain treatment with 0.3% Dryacide® (22±1°C, 70±5% R.H.)

Insects		Time of 100% mortality
O. surinamensis:	Adults	5th day
	Larvae	5th day
T. confusum:	Adults	13th day
	Larvae	13th week
E. elutella:	Adults	6th day
	Larvae	9th day
S. granarius:	Adults	(progeny → 7th week)

With the exeption of the granary weevil and the larvae of *T. confusum*, Dryacide® caused 100% mortality in all tested insects between the 5th and 13th day (Table 2). The stages of *O. surinamensis* and *E. elutella* reacted most sensitive to Dryacide. In these both species this DE had a clear insecticidal effect. Of *T. confusum* all tested adults died up to the 13th day after treatment, but a complete control of the larvae was only achieved after 13 weeks. Against *S. granarius* DE did not show satisfactory efficacy, because 49 days after the treatment beetles of the progeny hatched. However, the number of offspring was clearly reduced. While 836 beetles hatched in the untreated control only 23 beetles were found in the treated sample.

Also with the DE TEM 333® no complete control of *S. granarius* could be achieved (Table 3). Mortality was found to increase with increasing concentration of the dust, but in none of the tested dosages 100% mortality could be reached. The highest mortality achieved after 32 days was 63% at a concentration of 8% TEM 333®. After 12 weeks progeny was found in all treated grain samples.

Table 3: Average mortality of *S. granarius* in grain treated with TEM 333® and number of living insects after 12 weeks (100 granary weevils per glass, 20 ± 2 °C and 65 ± 2 % R.H.)

Dosage of TEM 333®	Mortality (%) after 32 days	Average number of beetles after 12 weeks
1 %	38	383
2 %	44	417
4 %	57	534
8 %	63	352
Untreated control	0	372

DISCUSSION

The larvae of *T. molitor* and *E. kuehniella* proved to be more tolerant to the DE than the adults. In *Ephestia* the larvae may have been protected from the dust by their cocoons. The larvae of the yellow meal worm were less mobile than the adults, which could be a reason for a reduced accumulation of the dust particles on the insect body.

The parameters relative humidity or moisture content are very important in this context. Higher R.H. or higher moisture contents could delay the desiccation process of the insects. Desmarchelier & Dines (1987) found in tests with Dryacide® that lower R.H. accelerated the desiccation of the insects. Also Carlson and Ball (1962) found that the mortality of *S. granarius* and *O. surinamensis* increased with decreasing moisture contents of the grain treated with inert dusts.

Both tested DE preparations , TEM 333® und Dryacide®, showed a low efficacy against the granary weevil. In spite of the high concentrations of TEM 333® (up to 8%) the beetles could not be controlled in the tested period of time. The efficacy of a DE preparation is to a great extent dependent on properties, like the particle size (Parkin, 1944), the amorphous or crystalline structure (David & Gardiner, 1950), the sorption ability (Melichar & Willomitzer, 1967) or the specific particle surface (White *et.al.*, 1975). A missing cooperation of all these factors could be a reason for the ineffectiveness of the DE preparations against *S. granarius*.

Because the immature stages of the granary weevil develop within the grain kernel, they cannot be reached by the DE. The tested dusts were not able to kill adult granary weevils fast enough in order to prevent reproduction within the tested time period. Further examinations will be necessary to examine different DE preparations and to compare their efficacy in controlling stored product pests.

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Control of nitidulid beetles in dried fruits by modified atmospheres

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ABSTRACT

Among the important pests of dried fruits are nitidulid beetles. Infestation starts in the field and unless control measures are employed, they and other pests continue to multiply and develop during storage. Methyl bromide (MB) has been used for fumigating dried fruits. However, because it is associated with the depletion of the atmospheric ozone, action has been taken to phase out its use in agriculture. This work was undertaken to develop a modified atmosphere treatment which would remove insects from the dried fruit. Dates grown in Israel served as a model for development of the technology.
Laboratory experiments were carried out to investigate the influence of different modified atmospheres (20% carbon dioxide in air or 2.8% oxygen in nitrogen), low pressures alone or MB alone in causing Nitidulid beetles to emigrate from infested dried fruit for which dates served as a model. At 4 h exposure and at 26°C, the treatments that had a marked influence in causing insects to abandon the infested fruit were: low pressure of 100 mm Hg and 2.8% oxygen in nitrogen, all of which caused over 80% of the initial insect populations to emigrate from the fruit.

Key words: Nitidulid beetles, dried fruits, modified atmospheres.

INTRODUCTION

Dried fruits are subject to infestation by insect pests during and after harvest. Several species of nitidulid beetles are particularly associated with dried fruits because they are field and storage pests. Fumigation of dried fruits with methyl bromide (MB) upon arrival at the packing plant effectively controls infestation and also causes a high proportion of larvae and adults to emigrate from the fruit before they succumb (Donahaye et al. 1991; Navarro et al. 1989). The mechanism of this emigration is not clear. MB has a delayed action on insects which is different from other fumigants that have an anesthetic effect and are termed indifferent narcotics (Price, 1985).

In recent years, reliance upon fumigation as an overall solution to infestation problems in durable agricultural products has become questionable. The chemical action of fumigants upon commodities and the environment has necessitated the withdrawal of many fumigants from the market. Of the two widely used fumigants, phosphine is characterized as a slow acting fumigant and insects develop resistance to it (Winks, 1987), whereas MB is under severe scrutiny because of its involvement in ozone depletion and as such the international community has decided to phase out its use (UNEP, 1995).

The influence of different controlled atmospheres (CA's) in causing emigration of *Carpophilus* spp. larvae from dates was compared with that of MB by Navarro et al. (1989)

and Donahaye et al. (1991). Recommended dosages for mortality of most stored product pests using CA are >60% carbon dioxide for at least 11 days exposure (Navarro et al. 1990). The influence of low O_2 or high CO_2 atmospheres as alternatives to fumigation of dried fruits has been investigated (Soderstrom, 1984; Soderstrom et al. 1986; Tarr et al. 1994).

Emigration from infested fruit is no less important than the toxic effect of the treatment because established tolerances set minimum acceptance levels for the presence of both dead and live insects.

In this study the effectiveness of a number of treatments and methyl bromide in causing emigration of *Carpophilus* spp. larvae from dates was compared. Initial experiments were undertaken on naturally infested or artificially infested fruit in which comparisons were made between different treatments; however, the material available was insufficient and was too heterogeneous to enable us to conduct investigations on the effect of parameters such as exposure time and concentration on treatments. Because of these difficulties, a series of experiments using artificial feeding sites were devised to determine whether larval on artificial site reacted to treatments similarly to larvae on fruit.

MATERIALS AND METHODS

Test insects consisted of larvae of *Carpophilus hemipterus* (L.) and *C. mutilatus* Erichson which were reared on media described by Donahaye and Navarro (1989). Cultures were obtained by placing adult beetles in 200 ml jars containing approximately 150 g of food medium chopped and mixed with sawdust. After allowing two days for oviposition, the adults were removed and larvae were reared in these jars until required. Cultures were held in a room at 26±1°C and 75±5% relative humidity (RH).

To obtain infested dates, mixed populations of *C. hemipterus* and *C. mutilatus* larvae were used. Dates were moistened in the laboratory to approximately 25% moisture content, placed in 2 L jars, larvae of both species were added, and cultures were incubated at 30°C for about one month.

All the treatments were carried out at 26±1°C. Humidity of the micro environment within the dates could not be controlled due to the heterogeneity of the experimental material but ranged from 70 to 80% RH, as determined by equilibrium RH measurements recorded in a sealed chamber using a humidity sensor (Nova-Sina, Model JEL-20, sensor Enmbrf-3, Novasina AG, Zurich, Switzerland).

Infested dates were exposed to different treatments in 2.54 L desiccators. Each treatment was exposed for 4 h.

The first treatment consisted of a dose of 16 mg/L methyl bromide. Dosage calculations were converted to the gaseous phase (Anon., 1981) and the required volume of methyl bromide gas was removed from a 25 ml screw cap septum vial (Mininert valves, Model 13074, Pierce, Rockford, IL) using a "Pressure-Lok" syringe (Series A-2, Model 050031, Dynatech Precision Sampling Corp., Baton Rouge, LA). The gas was then injected into the desiccator via a section of latex tube attached to the top of the desiccator lid and clamped at its distal end. The desiccator was then placed on a magnetic stirrer for 30 min. to obtain a uniform gas concentration.

The second treatment consisted of a 20% concentration of carbon dioxide (CO_2) in air: This mixture was delivered from an apparatus described by Donahaye (1990). The gas mixture was delivered to the desiccator through a capillary tube and the CO_2 concentration at the outlet was monitored by a gas meter calibrated for CO_2 (Model 20-600, Gow Mac, Bridgewater, NJ). The gas mixture was stirred during delivery, as described previously. When the 20% CO_2 level was reached, the desiccator was detached from the apparatus. The time needed to obtain 20% CO_2 in the desiccator was approximately 15 min.

The third treatment was a low pressure of 100 mm Hg. The low pressure was obtained using a laboratory vacuum pump and measured with a mercury manometer. For these experiments, pressure within the desiccator at the end of the exposure period was remeasured, and if a rise of more than 25 mm Hg above the initial pressure was recorded, the treatment was discarded.

The fourth treatment was an atmosphere of 2.8% oxygen (O_2) in nitrogen. This mixture (equivalent to the partial pressure of oxygen in air at 100 mm Hg) was obtained by evacuating the desiccator to 100 mm Hg. followed by restoration of atmospheric pressure using nitrogen.

The final treatment and control was ambient air at atmospheric pressure and $26\pm1\,^{o}C$.

The desiccators were fitted with false Perspex floors into which were drilled 5 mm holes, that separated each desiccator into upper and lower compartments. Before treatment, the dates and the feeding sites were cleaned of any external infestation and placed separately on the Perspex floor. Each desiccator was loaded with ten dates taken at random from the infested date supply. The dates were then exposed to treatment as described above, and upon completion of the exposure period they were removed from the desiccators and the larvae (dead or alive) present on the surface of the dates and at the base of the desiccators were counted. Then each date was opened lengthwise using a scalpel and the numbers of adults and larvae (dead or alive) still present in each date were counted. During exposure the desiccators were held in the dark at $26\pm1\,^{o}C$ and 75±5% RH. Each treatment was replicated at least four times and for each set of experiments a control desiccator was exposed to the normal atmosphere for the same time period.

The proportion of insects found outside the dates was used to measure response. Data were analyzed using a two way analysis of variance and significance of differences between the means was analyzed by least significant degree test (Steel and Torrie, 1980).

RESULTS AND DISCUSSION

The influence of different treatments on emigration from artificially infested dates and artificial feeding sites is shown in Fig. 1. Analysis of variance showed that emigration between treatments differed highly significant (F=167.822; df=4; P=0.00).

Emigration under the influence of MB, low atmospheric pressure, and low O_2 concentration were similar for the treatments. Results of these treatments differ significantly from the control and the CO_2 treated groups. The Carpophilus larvae appear to seek out and penetrate their food substrate through cracks and crevices and then remain largely sedentary, thus creating a niche in which they feed until abandoned when they begin to wander prior to pupation. Premature emigration from the feeding sites takes place under exposure to MB, low pressures, and low O_2 concentration. These treatments place the larva under stress, which interrupts

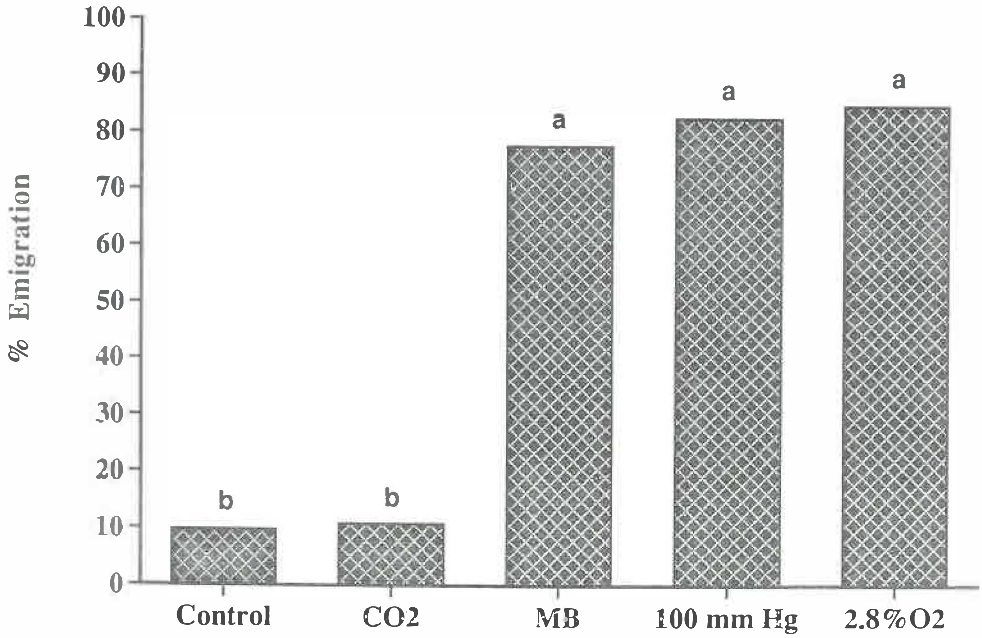

Fig. 1. Comparison of the influence of methyl bromide (MB) (16 mg/L), low atmospheric pressure (100 mm Hg), 2.8% oxygen (O_2), and carbon dioxide (CO_2) on the disinfestation of artificially infested dates after 4 h of exposure at 26°C. Emigration rates assigned a common letter do not differ significantly at $P<0.05$ (Navarro *et al.*, 1989).

feeding and causes them to wander. The similarity in the response of insects in the artificially infested dates demonstrate the validity of using these treatments.

A common characteristic of all the treatments tested in the present work is their capacity to cause eventual mortality, depending on the length of exposure. The modified atmosphere and low pressure treatments at the tested exposure periods in this study are known to permit high levels of insect survival, and only exposure times considerably longer than 24 h would cause mortality.

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Respiration rates of storage insects in airtight conditions

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ABSTRACT

Airtight storage for the preservation of cereals has been recognized as an effective storage method. This method targets taking advantage of respiratory metabolism of the insects and stops their damage on grain. *Tribolium castaneum,* at its four developmental stages was exposed to atmospheres containing 1 to 21 % O_2 that prevail in airtight conditions. All tests were carried out at 30 ^{0}C and 70 % r.h.
Results showed that insects required an initial acclimatization period of at least 5 h. At normal oxygen concentration, respiration of eggs was lower than that of other development stages while respiration of young larvae was the highest. At reduced oxygen levels respiration was proportional to the oxygen levels except the adult stage. Adult respiration was higher at 3 and 5 % O_2 than at normal atmospheric air.

INTRODUCTION

In the preservation of stored grains, modified atmosphere (MA) concept has been widely recognized and accepted as an alternative method to the environmentally toxic chemical measures (Bailey and Banks, 1975; Banks et al., 1980; Navarro et al., 1979; Navarro and Donahaye, 1990). Hermetic storage based on the bio-generation of a low oxygen and a high carbon dioxide atmosphere through insect respiration has been regarded as a promising method particularly for the small farmers in developing countries (Navarro et al., 1994).

The respiration rates of insect pests play an important role under reduced oxygen concentrations to enhance the effectiveness of sealed storage. The existing literature on the respiration rates of storage insects is very scarce (Birch, 1947; Donahaye, 1990; Edwards, 1953; Keister and Buck, 1974). This work was carried out with the objective of obtaining information on the respiration rates of development stages of *Tribolium castaneum* at low oxygen concentrations that prevail under sealed storage conditions.

MATERIALS AND METHODS

Modified atmospheres

The O_2 concentrations of 1, 2, 3, 5, 10, and 15% in N_2 were chosen for testing the respiration rates of the developmental stages of *Tribolium castaneum*. These O_2 levels were specially chosen since they constitute the O_2 compositions that can be obtained in sealed conditions. Normal air served as control.

Gas mixtures were obtained and humidified at 70% r.h. according to Navarro and Donahaye (1972).

Developmental stages

Eggs of 0-24 h old, young larvae of 7-10 d old after hatching, mature larvae of 18-22 d after hatching, pupa of 0-24 h old after pupation and adults of 14 d old after adult emergence were chosen for the experiment. Insect cultures were maintained according to Donahaye (1990).

Exposure flasks

Small bottles of 50-60 ml with 2 cm wide neck, equipped with silicon septa and aluminum lids were used. A crimper was used to seal these flasks tightly. Two syringe needles of 0.65X32 mm (N 14) were inserted through septa served as inlet and outlet of the gas mixture.

Exposure technique

The experimental flasks containing test insects were closed tightly and connected to the apparatus that supplied the gas mixtures. For experiments on larva and adults, 200 mg of food was added into the flasks before closing. A soap-bubble flow meter was used to verify and ensure the gas flow rates. After 24 h of conditioning period, a gas sample of 1 ml was taken and the inlet and outlet ports of the flask were blocked via metal clamps. 1 h later, another gas sample was taken. Gas concentrations were determined using a Tracer 565 gas chromatograph equipped with twin thermal conductivity cells, dual columns (each 4' *1/16'' id), and a sample loop which was thermostatically regulated at 50^0 C. Column 1 was packed with 'Porapak Q', while column 2 was packed with 'molecular sieve 5A'. Percent concentration of the gas components was computed by a Spectra Physics SP 4100 integrator.

RESULTS AND DISCUSSION

Preliminary experiments at normal atmospheric air showed that respiration of adults stabilized only after 5 h of exposure. Thus, it was decided to conduct the rest of the experiments after an exposure of 24 h of acclimatization period of all stages except eggs before gas sampling.

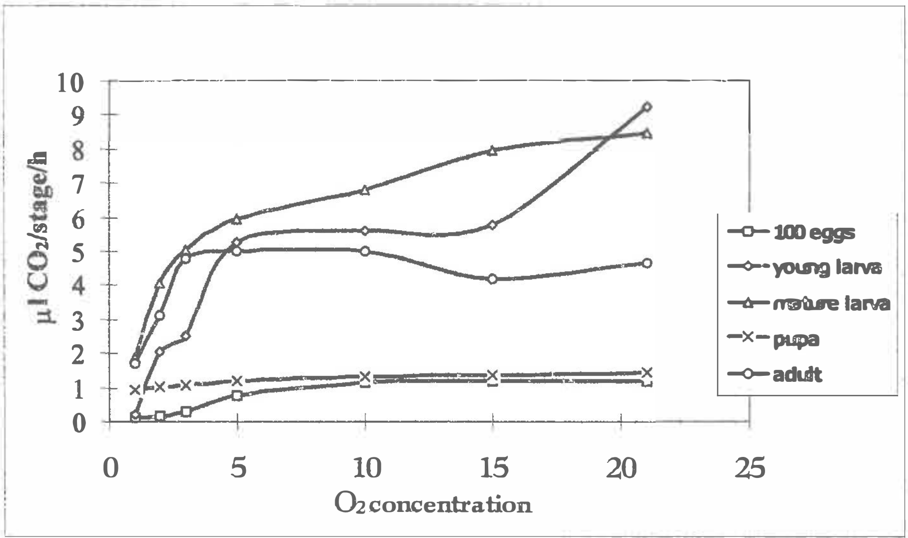
Results showed that the respiration rate of immature stages increased with increasing O_2 levels. CO_2 production in adults, however, was found to be high at 3-5% O_2 when compared to control values (Fig 1). RQ values for adults at the O_2 levels of 3, 5 and 21% were 1.07, 1.18 and 0.88, respectively.

Respiration of larvae tended to increase as the O_2 concentration rose from 1% to 21% while the rise in respiration rate was detectable only up to 3% O_2. Respiration rate of eggs was not detectable, while that for pupae did not markedly changed over the tested range of O_2.

At normal atmospheric air respiration rates reached the highest level in young larvae then steadily decreased till pupation and increased in adult after emergence. This kind of respiratory pattern was also reported in other insects (Birch, 1947; Campbell and Sinha 1978; White and Sinha (1981).

Respiration rates of young larvae were mainly suppressed at O_2 levels lower than 5% (Fig.1).

Fig 1. Respiration rates of the development stages of *Tribolium castaneum* at different O_2 levels at 30^0C and 70% r.h.



Respiration of eggs at 21% O_2 was nearly 9 times higher than at 1% O_2. In case of young larvae, this ratio was 42 times at the same O_2 levels. In young larvae, respiration was lower than that of old larvae at all O_2 levels except 21% (Fig. 1). Thus, at normal O_2 level young larvae produced more CO_2 than old larvae. Old larvae, however, expressed a similar respiratory response to the experimental O_2 levels, the ratio between the least and the highest CO_2 production rates was only 4.5 times.

Pupal respiration followed a similar pattern as previous stages did (Fig. 2). However, results indicated a less disturbance of pupal respiration at low O_2 levels. Respiration rate at 21% O_2 realized as 1.5 times higher than at 1% O_2 .

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Potential of acetone vapours for stored product pest control

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ABSTRACT

Acetone is a normal constituent of many organisms of plant and animal origin, including humans. The use of such a common natural compound for insect control purposes may be advantageous from the point of concerns about safety and environmental quality. Acetone vapours may act like fumigants and thus have the potential to kill various life stages of stored product insects. The results of the tests related to the effects of acetone vapours on the adults and eggs of the rice weevil, *Sitophilus oryzae* (L.), are presented. Four doses between 15.3-123.1 μl acetone/l air and four exposure periods between 1-4 days were used. A dose of 61.5 μl acetone/l air achieved 100 % mortality in 3 days in adults. However a shorter exposure, 1 day or less was required to achieve the same mortality at 123.1 μl acetone/l air. Only the latter dose caused 100 % mortality in the eggs.

INTRODUCTION

Fumigants are a unique and particularly valuable group of pesticides that kill insects where no other form of control is feasible. To a large extent they are irreplaceable (Bond, 1984). Particularly, there is no commercially viable alternative to methyl bromide where a rapid treatment is needed such as at import or prior to shipment and for quarantine. But its future use is under threat because it was placed on the list of ozone depleting substances. If methyl bromide is phased out as is targeted, only phosphine will be available for disinfestation of commodities and structural treatments in future since other fumigants were withdrawn in many countries because of suspected adverse effects (Bell, 1996).

An ever increasing demand for maximum protection of fumigators and for reduction of fumigant emissions places a heavy pressure on fumigation and renders it an increasingly expensive measure of pest control (Corunic, 1993).

In this context there is an urgent need to look for more selective, readily degradable and less harmful materials for control of pests of stored products. The nature is a vast source of such compounds. Acetone, a normal constituent of many organisms of plant and animal origin, including humans, is a good killing agent for insects infesting stored products when applied as vapour (Tunc et al., 1997). Acetone is well known for its various uses, particularly as a solvent. Several aspects regarding its safety and environmental fate were documented (Haggard et al., 1944; Gitelson et al., 1996; Anonymous, 1994). The use of such a compound, which is common in nature and therefore expected to be environmentally more compatible, for insect control purposes may be advantageous from the point of concerns about safety and environmental quality.

Though not a fumigant, acetone is a highly volatile liquid and therefore has the ability to act like fumigants. In this study, the insect control potential of acetone vapours is further emphasized. New data are presented based on its effects on the adults and the eggs of the rice weevil, *Sitophilus oryzae* (L.).

MATERIAL AND METHODS

S. oryzae was reared on wheat at 26±1° C and 65±5 % r.h. under continuous dark. Tests were also carried out under the same conditions. Acetone used in the tests was of 99.5 % purity (Atabay Kimya Sanayi Ticaret A.Þ., Istanbul, Turkey; Merck).

The adults (0-15 days after adult emergence) and the eggs (0-72 h old) inside the rice grains were exposed in nylon gauze bags. Twenty adults supplied with twenty wheat grains or forty rice grains supposedly containing eggs were put into each bag to make one replicate. Each dose x exposure time-combination was replicated three times and experiments were repeated twice.

Glass jars of 650 ml capacity with screwed lids were used as test chambers. Acetone was applied on a blotting paper strip measuring 2x8 cm and attached to the inner side of jar's lid by adhesive tape. Acetone doses of 15.4, 30.8, 61.5 and 123.1 μl / l air were applied by an automatic pipette. No material was applied in control jars. Exposure periods of 24, 48, 72 and 96 h were used. After exposure, bags were removed from the jars. Final mortality counts were made after 14 days in the adults and corrected for mortalities in the controls. Mortality of eggs was calculated on the basis of adult emergence in treated in proportion to adult emergence in controls. Mortality data were subjected to probit analysis to estimate LT_{50} and LT_{99} values (Sokal & Rohlf, 1969).

RESULTS

Acetone vapours were effective against the adults and eggs of *S. oryzae* (Table 1 and 2). For 99 % mortality at a dose of 61.5 μl acetone/l air 43 h were required in the adults whereas the time required for the same mortality at the same dose was much longer in the eggs which indicates that the eggs were more tolerant than the adults (Tables 1 and 2).

Adults emerged only from 8.8-10.7 out of 40 rice grains in controls. Due to uneven distribution of the eggs among the rice grains, inconsistencies are seen in mortality data for the eggs (Table 2)

DISCUSSION

In comparison to *S. oryzae* to the data obtained in this study, longer exposure periods were required for the same mortality at the same dose of acetone against the adults and eggs of the confused flour beetle, *Tribolium confusum* du Val (132 h, 71 h), and larvae and eggs of the Mediterranean flour moth, *Ephestia kuehniella* Zeller (> 70 h), respectively (Tunc et al., 1997). Thus the adults of *S. oryzae* were the most sensitive insect stage to acetone vapours among the species tested so far. The eggs of both *T. confusum* and *E. kuehniella* were, however, in contrast *to S. oryzae* more sensitive than the adults or the larvae, respectively.

Although the dose and the exposure period required for the desired mortality varies with the insect species and the life stage, acetone has the potential to control stored product insects with reasonable doses, e.g. 61.5-123.1 μl /l air and within reasonable exposure periods, e.g. 1-3 days.

Table 1. Mortality of *S. oryzae* adults exposed to various doses of acetone vapours for 24-96 h with LT_{50} and LT_{99} values

	%Mortality (mean±S.E.) Exposure periods(h)					
Dose μl acetone/l air	**24**	**48**	**72**	**96**	**LT_{50}(h)**	**LT_{99}(h)**
15.3	42.6±3.1	54.6±6.0	59.9±7.3	69.6±4.6	37.1	*
30.8	58.2±6.1	77.1±4.2	80.4±3.9	80.4±3.9	12.7	*
61.5	97.4±1.8	99.2±0.9	100	100	0.5	43.1
123.0	100	100	100	100	**	**
Control	4.2±1.5	2.5±1.1	2.5±1.7	2.5±1.7		

* Estimated LT_{99} values were too far beyond tested range to be reliable.
** Could not be calculated due to 100% mortality in all exposure periods tested.

Table 2. Mortality of *S. oryzae* eggs exposed to various doses of acetone vapours for 24-96 h with LT_{50} and LT_{99} values.

	%Mortality (mean±S.E.) Exposure periods(h)					
Dose μl acetone/l air	**24**	**48**	**72**	**96**	**LT_{50}(h)**	**LT_{99}(h)**
15.3	37.5±7.8	42.0±4.8	47.2±7.1	48.2±4.5	96.2	*
30.8	54.0±6.8	56.1±6.4	58.6±3.6	53.9±8.8	**	**
61.5	73.7±5.0	72.0±2.2	79.4±6.7	72.3±2.4	**	**
123.0	88.6±3.0	93.1±3.5	100	100	12.6	57.2

* Estimated LT_{99} values were too far beyond tested range to be reliable.
** Was not reliable due to inconsistency in data.

Since it has a relatively low acute and chronic toxicity (Howard, 1991) no risks are perceived from the emissions of acetone during and after application. A patient with coma due to drinking 200 ml pure acetone recovered with no serious consequences (Gitelson et al., 1966).

Inhalation of 6.4 μl acetone/l air for 8 h/day by humans performing moderate exertion was proposed safe (Haggard et al., 1944).

In the atmosphere acetone exists exclusively in the vapour phase. The two significant processes determining the fate of acetone in the atmosphere are reaction with hydroxyl radicals and photolysis. The estimated lifetime of acetone at latitude 40°N due to combined hydroxyl radical reaction and photolysis is 32 days/year (Meyrahn et al., 1986; *in* Anonymous 1994). Studies indicated that acetone is subjected to significant biodegradation in water and soil (Anonymous, 1994). Thus acetone is not expected to be environmentally persistent.

The main factor considered to effect the policy of further application of fumigants, that are concerns about the fate in the atmosphere and the impact of very low concentrations on people (Corunic, 1993), should be of minimal importance so far acetone is concerned.

Fire is the major hazard of acetone because its vapour flammability limits are 2.6-12.8 vol. % in air and flash point is low,-18°C (Howard, 1991). However, flammable compounds are not necessarily excluded if dangers of fire and explosion can be controlled by the addition of other suitable compounds, or if applications are carefully designed to eliminate these hazards (Bond, 1984).

We do not have any information on the penetration, sorption and desorption of acetone vapours in the bulk of commodities. Information on possible chemical reactions with compounds in the stored product and on the effects on nutritional, organoleptic, processing and seed qualities is also lacking. However, we feel that investigations on the suitability of acetone, at least for space treatments, are worthwhile where higher standards of safety and environmental quality are sought.

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