

When stored product protection involves contract services rather than doing everything internally, there will be transactions costs. The goal is to minimize these costs. Government and industry standards such as EPPO in contracts avoids negotiations cost over certain technical matters. Government licensing of suppliers to ensure minimum quality and recourse for poor performance, and infrastructure that makes market information readily available (directories and advertisements are examples) can reduce transactions costs. Search costs can be avoided by using a contractor who has proven reliable and affordable in the past. The more valuable in total the product being protected and the greater the price for say fumigation or packaging, the more willing you should be to engage in additional search. The economic principle telling you when to stop incurring search costs is marginal search costs should never exceed expected savings on the transaction.

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08 - Prospects for biological control of stored-product pests

Schöller, Matthias

Biologische Beratung Ltd.
Storkower Str.55, 10409 Berlin, Germany

Abstract

Natural enemies are applied commercially against stored-product pests in Central Europe. In this contribution, an overview about the fields for application of the beneficial insects are given. The mode of action of beneficials is compared with the application of chemical pesticides. Examples for successful biological control include the retail trade, the food processing industry, storage on farms, bakeries and mills. Both conventional and organic producers apply beneficials. The main target pests are moths and beetles. Pest control companies gain in importance as operators of biological control. The prospects for biological control as a component of IPM is discussed.

Introduction

Do natural enemies exert stress on chemical products? Fewer synthetic chemical insecticides are available for the protection of stored products (Reichmuth, this volume; Arthur & Rogers, 2003). This leads to an increased interest in alternative control options, including biological control by mass-reared natural enemies that are now commercially available (Prozell & Schöller 2003). But does the availability of beneficials again result in a decrease of synthetic chemical insecticide application? To shed light on this aspect, three questions have to be addressed: (1) is there an overlap of fields of application of beneficials and chemical insecticides? (2) is the control effect comparable? and (3) are there enough laboratory-reared natural enemies available to replace chemical insecticides? Let us first look at the main areas of commercial application to see if an overlap of fields of application exists.

The main areas of commercial application of natural enemies: In stored products, parasitoids are mainly applied against stored-product Pyralid moths and stored product beetles (Stengård Hansen, 2005; Schöller et al., 2006). The natural enemies are reared in the laboratory (augmentative release strategy) and released as pupae or adults in the target sites (Prozell & Schöller, 2003). Typically, inundative releases are advisable, i.e. relatively large numbers of beneficials are repeatedly released.

Control of stored product moths: Both parasitoids against stored product moths eggs and larvae are commercially available. Egg parasitoids of the genus *Trichogramma* typically have a fairly broad host range and attack the Indian meal moth, the Mediterranean flour moth, the warehouse moth as well as many other moths species. The egg parasitoids are usually released as pupae attached to egg cards at the rate of at least 500 females per linear meter of shelving, although higher release rates may be needed for situations where shelving is more than 2 m in height (Grieshop et al., 2006a). The individual *Trichogramma-wasp* is shortlived (2-6 days). Modern release units contain a mixture of developmental stages resulting in the staggered parasitoid emergence over a period of three weeks, or in the case of *Trichogramma evanescens* allow even the presence of egg parasitoids over 4 weeks. Given a release period in unheated storage buildings in Central Europe from mid of April to mid of October, a total of only 9 or 7 releases are necessary, respectively (Fig. 1).

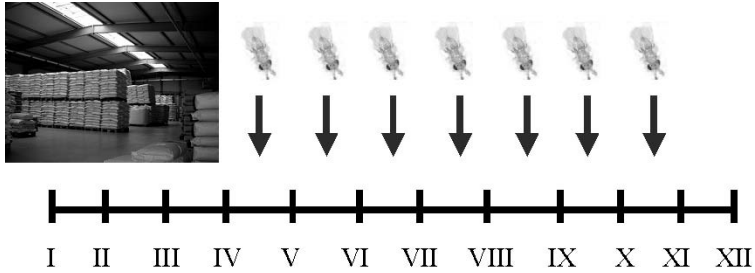


Fig. 1 Timing of release for *Trichogramma evanescens* from 4-week activity release units against moth eggs in a bag store.

Trichogramma spp. are typically released to prevent previously uninfested packaged products from infestation by moths (Grieshop et al., 2007). It is therefore a preventative method. A potential limitation of *Trichogramma* spp. is that their foraging success may be severely limited in situations such as spills or bulk product where small scale habitat complexity hinders the finding of the moth eggs. In this situation *Trichogramma* spp. can be combined with the larval parasitoid *Habrobracon hebetor* (Grieshop et al., 2006b). *H. hebetor* attacks the “wandering” last instar larvae and diapausing larvae and is relatively larger than *Trichogramma* spp. (about 5 mm in length). *H. hebetor* are released as adults or pupae at a rate of 25-50 females per 10 square meters of storage room. As *H. hebetor* are strong fliers with good long-range searching ability (Strand et al. 1989) and females can live up to two weeks they provide a relatively good “residual effect”. *H. hebetor* is capable of penetrating compromised packages and parasitizing wandering larva prior to their exit, potentially reducing the spread of moth infestations within a facility (Schöller et al., 2006). An example for the combination of the egg parasitoid with the larval parasitoid is given in Fig. 2, e.g. for heated mills and bakeries.

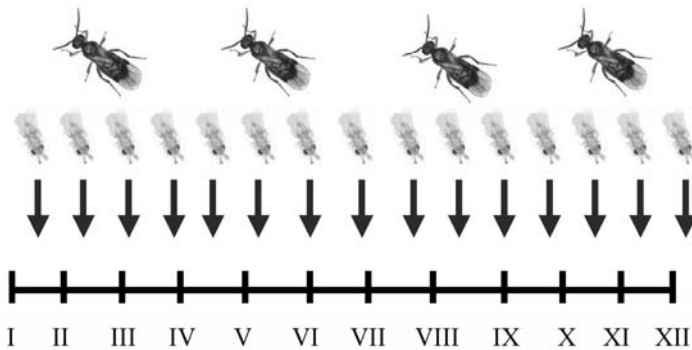


Fig. 2 Timing of release for *Trichogramma evanescens* from 3-week activity release units against moth eggs (15 releases) and *Habrobracon hebetor* (4 releases) in a bakery.

Biological control of stored-product moths allows the presence of workers or clients during the treatment time. The major advantage of *Trichogramma* spp. in this context is their extremely small size (> 0.5 mm in length) making the parasitoids virtually invisible to the casual observer.

In bulk grain, a combination of *Trichogramma* spp. and *H. hebetor* is recommended, too. Experience with this system is available for small-scale farms, with silos or boxes with grain ranging from 10 to 100 tons. *Habrobracon hebetor* is released in early spring when temperatures reach 12-15°C, and again in July to October depending on the presence of wandering larvae. *Trichogramma evanescens* is released from June to August depending on the presence of adult moths (Fig. 3). The release of parasitoids in large warehouses (800 t to 1200 t grain) is currently under study.

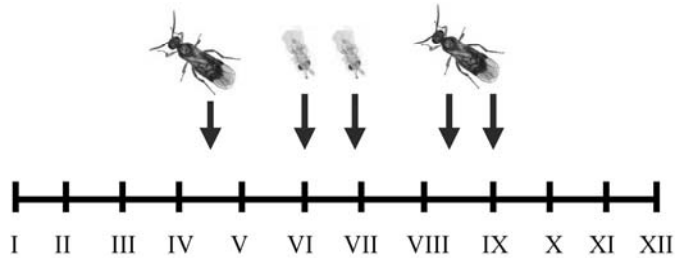


Fig. 3 Timing of release for *Trichogramma evanescens* from 3-week activity release units against moth eggs (2 releases) and *Habrobracon hebetor* (3 releases) in bulk grain.

Control of stored product beetles: The commercial application of natural enemies against stored product beetles diversified in recent years. The main application is still in grain storage on organic small-scale farms, but control of material pests is gaining importance, too.

Females of the pteromalid wasps *Lariophagus distinguendus*, *Anisopteromalus calandrae* and *Theocolax elegans* lay their eggs on host larvae or pupae inside grains or cocoons. For this purpose, the ovipositor is inserted and the host larva is paralysed prior to oviposition. After emergence from the egg, the parasitoid larva feeds on the host larva from the outside, thereby killing it. The bethylid wasp *Cephalonomia tarsalis* parasitises larvae of *Oryzaephilus* spp., the eggs are laid externally on host the larva after paralyssation, too.

Empty room treatment: A mixture of the chalcid parasitoids *Lariophagus distinguendus* and *Anisopteromalus calandrae* is recommended at a dose of 30 females per 10 m² against beetles. Empty grain stores are best treated 2 - 6 weeks prior to loading of grain. Herb stores were treated between mid April and mid of October against the warehouse beetle *Stegobium paniceum*, and pasta factories all year round against *Lasioderma serricorne* and *Sitophilus zeamais*.

Similarly, the bethylid wasp *Cephalonomia tarsalis* is applied against the sawtoothed grain beetle *Oryzaephilus surinamensis* in stored grain environments, and against *Oryzaephilus mercator* in chocolate-producing companies.

Bulk grain: The parasitoid *Lariophagus distinguendus* alone or in combination with *Theocolax elegans* is recommended at a dose of 30 females per 15 t grain against *Sitophilus* spp. weevils. These two parasitoids were proven to enter into the grain bulk. The host-finding ability of *L. distinguendus* was examined under realistic conditions of application. In a silo bin and a flat storage grain box, adult parasitoids were released at the surface. The parasitoids were able to find and parasitize hosts located up to 4 m vertically and horizontally from the release point (Steidle & Schöller, 2001). The parasitoids are either released in spring when temperatures reach 15°C, or 4 weeks after loading the grain until autumn (Fig. 4), or according to the modeling software Sitophex (Prozell et al., 2004). Similarly, the bethylid *Cephalonomia tarsalis* is applied against the sawtoothed grain beetle *Oryzaephilus surinamensis*.

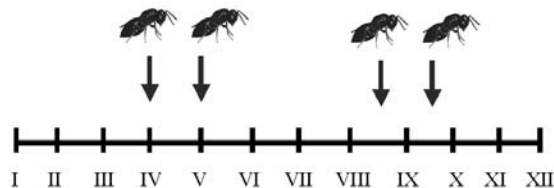


Fig. 4 Timing of release for adult *Lariophagus distinguendus* against weevil larvae (4 releases) in bulk grain.

Most recently, the biological control of the golden spider beetle *Niptus hololeucus* and the hump beetle *Gibbium psylloides* in historic buildings reached the commercial stage after years of tests in practice. The parasitoid applied is the store chalcid *Lariophagus distinguendus* that was known as natural enemy of the respective beetles for many years (Kashef, 1961), but never evaluated for biological control.

Efficiency: Is the control effect of parasitoids and chemical products comparable? In case an egg, a larva or a pupa of a stored product pest insect is stung by a parasitoid, it does not recover and dies. This is typically even the case when no eggs are deposited by the parasitoid (e.g. Hase, 1924). In this case, the control efficiency of the parasitoid is 100%. Consequently, for the evaluation of the biological control effort the crucial question is whether the parasitoid and its host, the stored product pest, meet or not. Two important criteria in this respect are temperature limits for activity of the parasitoid and its host, and host-finding behaviour of the parasitoid. For some parasitoid-host systems, it was shown that the parasitoids tolerate similar low and high temperatures as their hosts. In Central Europe, the lower temperature limit is of special importance because it is important to suppress the pest population early in the storage season. For example, in laboratory trials the granary weevil parasitoid *Lariophagus distinguendus* was found to completely develop at 15.8°C (Stengård Hansen, 2007a). Recent investigations in the laboratory and in stores indicate an even lower temperature limit of 9°C to 10°C for parasitisation and therefore control of the weevils (Niedermayer & Steidle, 2009). The lower temperature limits for complete development of the granary weevil *Sitophilus granarius*, the maize weevil *S. zeamais* and the rice weevil *S. oryzae* are 15°C, 17°C and 17°C, respectively (Weidner, 1983). Different species and strains of the genus *Trichogramma* differ significantly concerning their tolerance for low temperatures. One of the reasons for the selection of *Trichogramma evanescens* euproctidis for the control of stored-product moths in Central Europe was its parasitisation activity at 15°C (Schöller & Fields, 2003). Performance at low temperatures is only one of many potential parameters to select a suitable beneficial for biological control. A list of criteria to select natural enemies for inundative biological control of stored-product moths was suggested by Schöller & Flinn (2000). The selection of the most effective natural enemy is a step prior to commercialisation of natural enemies undertaken to ensure a sufficient efficiency. So far, no case of resistance of stored product pests to natural enemies is known, but there are many examples of a loss of quality of mass-reared natural enemies. Consequently permanent quality control is necessary to keep the control efficiency.

In case natural enemies are applied as a prophylactic treatment and no infestation of the products occur, it is hard to determine if this is due to the control effect of the natural enemies or not. However, if the stored product pests were present e.g. on a farm for many years and no more infestation is detected after the release of parasitoids, this is generally attributed to biological control.

Tab. 1 Comparison of selected biological and chemical control strategies in Central Europe.

Target site	Biological control	Chemical control	Pest / Stage	Application time in Central Europe	Prophylactic treatment
Empty room, Bag store	<i>Trichogramma evanescens</i>		pyralid moths / eggs	April - October	yes
		contact insecticide, e.g. Pyrethrum + PBO	pyralid moths / adults	April - October	no
Bulk grain and empty room grain store	<i>Habrobracon hebetor</i>		pyralid moths / larvae	March - December	yes
	<i>Lariophagus distinguendus</i>		some beetles / larvae	April - October	yes
		diatomaceous earth	beetles / adults and larvae (partly)	April - October	yes
		contact insecticide, e.g. Pirimiphos-methyl	beetles / adults and larvae (partly)	April - October	no

Capacity - are there enough natural enemies produced? Macroorganisms for biological control like parasitoids and predators are still produced by rearing the host or prey species in the laboratory or in green houses first. Artificial media for rearing of natural enemies are still not effective enough for commercial application. This fact and the limited shelf-life of the products, i.e. the short time parasitoids and predators can be kept refrigerated without losing their viability severely limits the mass-production of beneficials. Beneficial insects and mites are manufactured, not produced on an industrial scale. This might be one of the reasons why comparatively few companies produce natural enemies. The world-wide production of beneficials for stored product protection is currently restricted to the three European countries Germany, the Netherlands and Switzerland. However, the recent example of the remarkable increase in the use of beneficials for protected crops located in the South of Spain within only few years showed that the biocontrol market is able to respond to the need of customers.

Conclusions

Typically, biological control acts slowly as one or few developmental stages of the pest are attacked only. Moreover, most beneficials are specialised on the attack of few pest species. The exact determination of the pest species is therefore necessary. Constant monitoring of the pest population is also required. An advantage compared

to chemical control is the possibility to produce while natural enemies are active, because neither the production process nor the workers are affected by the presence of beneficials. Several application strategies of beneficials are not paralleled by those of insecticides, like the protection of packages from infestation by moths, the control of diapausing moth larvae by *Habrobracon hebetor* or the application in organically producing companies (Schöller & Prozell, 2007). Among the few applications that might be completely replaced by the release of beneficials due to incompatibility (Perez-Mendoza et al., 1999) are diatomaceous earth and/or powder formulations of contact insecticides for the control of spider beetles in historical buildings.

At the last international forum on stored product protection, Helbig (1996) estimated the potential of biological control methods for various pest species and types of stored products. At that time, biological control agents were not commercially available yet. Tab. 2 compares the 1996 estimate with the current commercial application of parasitoids. The most striking difference concerns food for human consumption, the acceptance of the release of living insects for biological control close to food items in private households, wholesale stores and processing plants was not expected. The application of parasitoids in these areas reflect a change in attitude in part of the public, rating the risk of contamination of food with parasitoid wasps less dangerous to health compared to the risk of contamination of food with synthetic insecticides. In fact, scientific studies (Flinn & Hagstrum 2001, Ambrosius et al., 2005) have shown that the appropriate application of natural enemies does not lead to contamination of food with parasitoid wasps, either because raw materials for production of food are cleaned prior to processing or because the pests are controlled outside packaged food.

Tab. 2 Criteria for the use of biological control of stored product pests. Estimation for the potential of application by Helbig (1996) and current commercial application; + = high potential, 0 = intermediate potential, - = low potential

Criterion	Category	Potential according to Helbig, 1996	Current commercial application
Pest species	Lepidoptera	+	+
	Coleoptera	0	+
	mites	-	-
Beneficial	parasitoid	+	+
	predator	+	0
	pathogen	-	-
Type of product	fodder	+	0
	raw material for industrial processing	+	+
	raw material for production of foods	0	+
	foods	-	+
Type of store	Large scale store	-	+
	Small scale farmer store	+	+
	Processing industry	0	+
	Food wholesale trade	0	+
	Food retail trade	+	+
	Private household	-	+
Type of storage	Bulk	+	+
	Packed products	+	+

While the release of the parasitoids itself is easy and does not require skilled workers, the decisions when and where to release are not. Like with any other control technique, the storage situation has to be analyzed and the foreseen storage or processing steps taken into account. Currently pest control companies gain in importance as operators of biological control. If the situation is appropriate, biological control is a valuable option differing in the mode of action from physical or chemical methods mostly by the fact that natural enemies actively forage for stored product pests in hidden places.

As many more natural enemies of stored product pests are known (Schöller 1998) than are currently commercially reared for biological control, there is still a lot of potential for new biological control strategies. Biological control can reduce the number of pesticide applications rather than replace existing chemical control strategies. Chemical products are not expected to vanish due to their replacement by natural enemies, but due to the lack of sustainability of the concept of neurotoxic contact insecticides (health risks) or due to adverse effects on the environment as in the case of some fumigants (MBTOC, 2002). In contrast, more potential of integration of chemical and biological control exists for conventional stored product protection.

The European working group funded by the COST system (2000-2005) identified three situations where biological control would be a valuable component of integrated pest management: (1) empty room treatment (2) preventative treatment of bulk commodities, in particular grain, using parasitic wasps and predatory mites against weevils and

storage mites and (3) preventative application of egg-parasitoids of the genus *Trichogramma* to protect packaged products from infestation by moths (Stengård Hansen, 2007b).

Modern pest control operations combine or ideally integrate different control methods. A wide variety of different control methods support therefore the possibility to find solutions for complex control situations (Stengård Hansen, 2007b). The definition given by Reichmuth (1996) at the last international forum on stored product protection still sets the frame for the prospects for biological control of stored-product pests: „An Integrated Pest Management System (IPM) in stored product protection comprises 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”.

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09 - Some like it hot – some not: Differences in temperature preference of two parasitic wasp species

Niedermayer, Steffi; Steidle, Johannes L.M.

University of Hohenheim
Garbenstr. 30, 70599 Stuttgart, Germany

Abstract

Insect pests not only cause damage to crops in the field but also to stored products. One of the major pests in stored grain in Europe is the granary weevil *Sitophilus granarius* (L.).

The most commonly used biocontrol agent against this and other pests developing inside kernels or cocoons is *Lariophagus distinguendus* (Förster) a parasitic wasp belonging to the family of Pteromalidae. Another parasitic wasp of that family is *Anisopteromalus calandrae* (Howard). Even though the two wasp species show very similar host finding and parasitisation behaviour, field experiments reveal that *L. distinguendus* and *A. calandrae* have different temperature requirements. Whereas parasitisation in *L. distinguendus* can already be observed at weekly mean temperatures of 9°C to 10°C, *A. calandrae* needs weekly mean temperatures of at least 11°C to 12°C. On the other hand, *L. distinguendus* is affected by high temperatures more easily than *A. calandrae*. Laboratory experiments under different constant temperatures confirm this finding. These findings suggest a temperature dependent release of either *L. distinguendus* or *A. calandrae*. At mean temperatures below 19°C, *L. distinguendus* should be used, at higher temperatures *A. calandrae* performs better.

Introduction

Insect pests are a threat to stored products. Despite preventive methods such as ventilation and cleaning infestations with stored product pests can not always be avoided. These pests are not only responsible for losses in weight and quality but can also cause health problems. With the rapid decline of available active substances against stored product pests in the last couple of years, especially the phase out of methyl bromide in 2005, a huge challenge is posed for pest control in the future. Alternative methods such as the use of sulfuryl fluoride, controlled atmospheres and heat treatment require sealed buildings or bins with a high degree of gas tightness and are often cost and energy