Section: Non-Chemical Control

Biological control of stored-product insects in commodities, food processing facilities and museums

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DOI: 10.5073/jka.2010.425.167.165

Abstract

Non-chemical control methods have gained importance in integrated pest management, as policies aiming to minimize the application of residual chemical insecticides are being adopted by many companies, and a growing market of organic produce. The associations of organic farming have established self-restrictions concerning chemical control. Examples are given of how organically producing farms and processing companies function without synthetic chemical pesticides. Both non-chemical control methods for complete disinfestations and for suppression of re-infestation or residual infestations are needed. For complete disinfestations, heat treatment of buildings is now more widely used. Data on heat-tolerance of stored-product pests and an example for a heat treatment of a mill will be given. For high-value products such as spices, tea or medical plants, deep freezing is applied. Temperature data are needed to apply product-specific freezing conditions to obtain complete control at the core of the bulk. An integrated management strategy is needed to keep products free from infestation following disinfestations, along the whole chain from the storage of raw products to the consumer. Biological control is a part of that strategy. A new branch of the biological control industry is developing in Europe. Natural enemies for stored-product pests are now produced in The Netherlands, Germany and Switzerland. Traditional pest control companies are using insect parasites and predators more and more to control stored-product insects, indicating an adoption of biological control. Homeowners throughout Europe are purchasing online *Trichogramma* sp. to control moth pests. Biological control is especially attractive to processing facilities that are not willing to stop production for pest control operations. Small farms with bulk grain stores that are not gas-tight apply parasitoids as well. Recommendations for the application of natural enemies are presented for these examples. Finally, recent developments on natural enemies both for stored-product pests, e.g. flour beetles, and museum and wood boring pests are presented.

Keywords: Stored-product Pests, Material Destroying pests, Temperature modification, Biological control

1. Introduction

Non-chemical control methods have gained importance in integrated pest management, as policies aiming to minimize the application of residual chemical insecticides are being adopted by many companies, and a growing market of organic produce. Governmental and international regulations, and loss of synthetic insecticides such as methyl bromide (Fields and White, 2002) and greater restrictions on the use of dichlorvos, have left few alternatives for even non-organic food processors. In this review, non-chemical control strategies are reviewed focusing on biological control.

2. Non-chemical disinfestations

In many cases, the control of stored-product pests requires the control of large numbers of pest individuals hidden in large amounts of product or structurally complex buildings. For complete disinfestations, temperature modification is the method of choice. Heat treatment of buildings is becoming more widely used in North America and Europe (Fields, 1992; Burks et al., 2000; Dosland et al., 2006; Adler, 2007). Typically rooms are heated and the temperature is kept constantly at about 50 to 60°C for 24 h. Facilities up to 100,000 m^3 are treated (Hofmeir, 2002). For high-value products like spices, tea and medicinal plants, deep freezing is applied. Product-specific temperature data is needed for the freezing conditions to obtain complete control at the core of the bulk (Burks et al., 2000). For bulk grain, aeration is a basic component of non-chemical pest control (Reed and Arthur, 2000). Additional options for the processing industry are vacuum (Calderon et al., 1966; Mbata et al., 2004), steam and vacuum (Prozell and Schöller, 2004), impact (Plarre and Reichmuth, 2000), and last but not least, sanitation and exclusion (Imholte and Imholte-Tauscher, 1999; Mullen and Pederson, 2000).

3. Biological control

Several reviews have been published on the use of pathogens, and insect parasitoids and predators to control stored-product insect pests (Arbogast 1984 a,b; Haines, 1984; Brower, 1990; Nilakhe and Parker, 1990; Brower, 1991; Burkholder, 1981; Burkholder and Faustini 1991; Brower et al., 1996; Schöller et al., 1997; Schöller, 1998; Schöller and Flinn, 2000; Schöller and Prozell, 2006; Schöller et al., 2006). In this contribution, some results are summarized that were published since the last review, especially for fields that were identified as major challenges for stored-product biological control; control of *Tribolium* spp. in food processing facilities and material destroying pests.

3.1. Parasitoid biology

A number of films on the biology of parasitoids attacking stored-product pests are now available online (http://www.entofilm.com), namely *Habrobracon hebetor* (Say) vs. *Ephestia kuehniella* Zeller, *Cephalonomia tarsalis* (Ashmead) vs. *Oryzaephilus surinamensis* (L.), *Lariophagus distinguendus* (Förster) vs. *Sitophilus granarius* (L.) and *Trichogramma brassicae* Bezdenko vs. moth eggs. These films revealed interesting insights into the behaviour of the parasitoids, for example it was shown that *H. hebetor* builds a short feeding-tube when feeding on the body content of the host larva (Fig. 1).

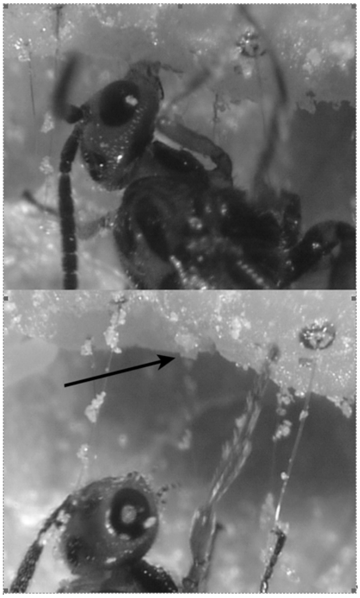

Figure 1 *Habrobracon hebetor* host feeding tube (Wyss et al., 2007).

3.2. Long-term control with natural enemies

A number of retail shops, wholesale stores, bakeries, mills and food processing companies have used parasitoids against stored-product moths continuously for 10 to 15 years in Germany. Even so monitoring for moths was documented with the help of pheromone traps, it is not easy to obtain comparable data rows for such long periods. Larger facilities are generally more suitable for data collection, because more traps are used and bias due to invasion of pests from outside as well as the impact of few infested packages is generally less pronounced. However, mills, bakeries and food processing plants typically undergo many changes in their production units, machinery or even floor plans, resulting in the need to adapt the monitoring plan and making it difficult to compare from one year to the next. There are few studies in facilities that have remained unchanged, and these offer a unique opportunity to study the population dynamics. An example is a bakery where *Trichogramma evanescens* Westwood was released at a rate of 25,000/week and *H. hebetor* at a rate of 100/month (Schöller et al., 2006). The number of *E. kuehniella* caught in pheromone baited funnel traps decreased over time and was reduced below 15 moths/trap-month during the last four years (Fig. 2). This example shows that it is possible to manage stored-product moths in a bakery without synthetic chemical insecticides.

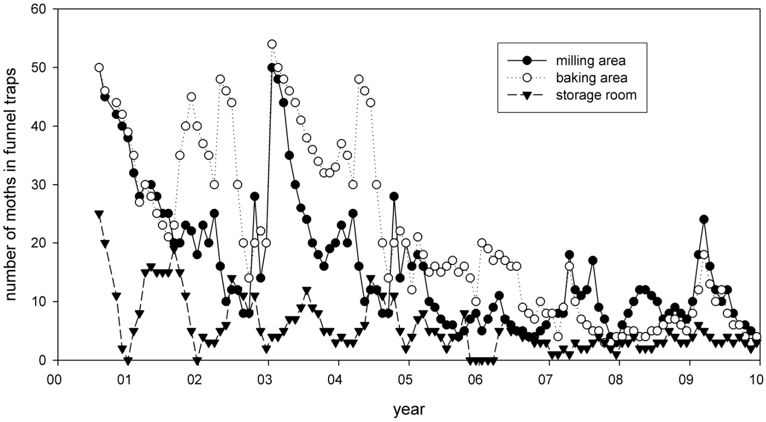

Figure 2 Number of moths in funnel traps in three areas in a bakery in Rhineland-Palatinate, Germany, from 2000 to 2010 (Schöller et al., 2006).

3.3. Future of biological control in stored-products revisited

The evaluation of biological control of stored-product pests in Europe was supported by a five-year COST (European Cooperation in Science and Technology) project. This project allowed a group of researchers to meet on a regular basis and also funded research projects (Hansen and Wakefield, 2007). Proceedings from the meetings are available at http://cost842.csl.gov.uk. A final resolution (Hansen, 2007) was prepared and signed by twenty-six researchers from sixteen European countries that identified the following situations where biological control hold most promise:

1. Empty room treatment using predatory mites, parasitic wasps and entomopathogenic fungi against stored-product mites, beetles and moths,
2. Preventative treatment of bulk commodities, in particular grain, using parasitic wasps and predatory mites and,
3. Preventative application of egg-parasitoids of *Trichogramma* spp. to protect packaged products from infestation by moths.

In the last extensive review of biological control of stored-product pests (Schöller et al., 2006), a number of challenges were listed in the paragraph “future of biological control in stored products”. The following two paragraphs will address recent developments concerning these issues.

3.3.1. Release guidelines for natural enemies

The development of effective release guidelines for natural enemies has been an important issue in biological control. Because the same species of pest may be found among a wide variety of storage systems, this area of research is especially important for management of stored-product pests. The number of beneficial insects to be release and correct timing with host phenology is an area that requires additional study. Both host and natural enemy phenologies need to be studied under a variety of environmental conditions in order to optimise the timing of release. Biological control of stored-product moths was the first area of commercial application of parasitoids. Both egg and larval parasitoids have been used. *Habrobracon hebetor* is a gregarious ectoparasitoid of Pyralid moth larvae. Female *H. hebetor* parasitises the larvae of several species of stored-product moths, including Indianmeal moth

Plodia interpunctella (Hübner), Mediterranean flour moth *E. kuehniella*, warehouse moth *Ephestia elutella* (Hübner), and the tropical warehouse moth *Cadra cautella* Walker. *Trichogramma* spp. are small endoparasitoids of lepidopteran eggs. The major advantage of *Trichogramma* species is their extremely small size; with adult egg parasitoids measuring only 0.3 mm in length, making them virtually invisible to the casual observer. *Trichogramma* spp. lay their eggs in lepidopteran eggs, killing the developing moth embryo prior to hatching, and therefore preventing the damaging larval stage. The parasitoid larva consumes the contents of the moth egg, pupates, and emerges as an adult wasp in 7 to 14 d (Grieshop et al., 2007). *Trichogramma* spp. are usually released as pupae glued to egg cards at the rate of at least 500 females per card, and one card per linear meter of shelving. Higher release rates may be needed for situations where shelving is more than 2 m in height. Because *Trichogramma* usually does not become established, release units should be applied in a way that guarantees continuous presence of the parasitoids. To facilitate this, commercial insectaries offer release cards containing overlapping cohorts of insects resulting in a staggered emergence of *Trichogramma* spp. parasitoids over a 2-wk period, a 3-wk period, or even a 4-wk period when released from a new release card developed in 2009. Figure 3 shows the number of releases per year for these systems. It is advantageous because store-keepers or pest control operators spend less time for changing the release units. Moreover, in many cases pest control operators visit stores monthly for pest monitoring and rodent control, so the new release unit fits to this schedule . Moreover, Figure 3 shows the recommended monitoring for the timing of the releases. Pyralid moths are monitored with the help of pheromone-baited traps. In temperate regions, the Indianmeal moth enters diapause, usually from November to April, consequently no *Trichogramma* should be released during this period. During the period of diapause, the larval parasitoid *H. hebetor* can be released to obtain a further reduction of the moth population.

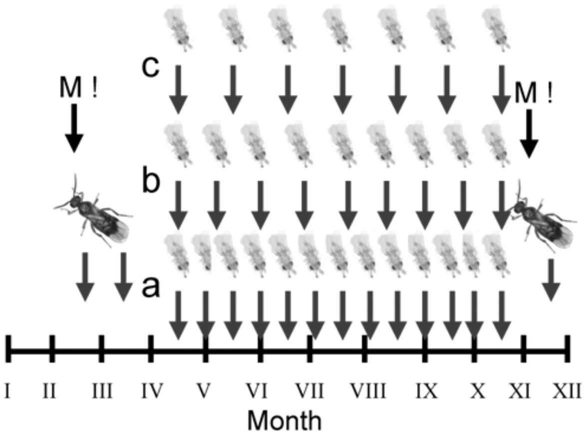

Figure 3 Management strategies for biological control of diapausing stored-product pyralid moths in temperate regions; large wasp = *H. hebetor*, small wasp = *Trichogramma evanescens,* a = *T. evanescens*, 2-week release unit (RU), b = 3-week RU, c = 4 week RU; “M !” indicates monitoring-action needed to time schematic release of parasitoids.

Discussion is still going on whether *L. distinguendus* or *Anisopteromalus calandrae* (Howard) is more suitable for control of *Sitophilus* spp. in bulk grain. For temperate regions, *L. distinguendus* was thought to be more effective due to its comparatively greater tolerance towards cooler temperatures, and the penetration into the grain column was shown to be very effective (Steidle and Schöller, 2001). Hansen and Steenberg (2007) found greater suppression of *S. granarius* in units with 9 kg wheat and *L. distinguendus* compared to units treated with *A. calandrae* at 20°C. Recently Niedermayer and Steidle (2007) suggested that *A. calandrae* should be more effective in summer, due to its shorter generation time. Moreover, *Theocolax elegans* (Westwood) was released against *S. granarius* in Central Europe (Schöller and Prozell, 2007). More field studies are needed to find the optimum release strategy for pteromalid wasps against weevils in bulk grain.

Release guidelines have been developed for other storage situations (Schöller and Prozell, 2006), but much more research, especially field studies are necessary to explore the potential of natural enemies for biological control of stored-product pests. Moreover, there are no official guidelines for the application of natural enemies to durable stored products, although the first studies in this field date back to the 1920's.

3.3.2. Progress in promising fields of application: Tribolium spp.

The discovery and development of natural enemies for the flour beetles *Tribolium castaneum* (Herbst) and *Tribolium confusum* Jaquelin du Val has been identified as a major challenge for stored-product biological control (Schöller et al., 2006). This is of particular interest for flour mills that have recently lost the use of methyl bromide, their major tool for control of this insect. Future biological control of flour beetles was thought to depend on foreign and domestic exploration for new species of natural enemies as well as trying to find effective rearing methods for the parasitoid wasp *Holepyris silvanidis* (Brèthes, 1913). In fact, an improved rearing method for *H. silvanidis* was found. Currently two approaches are followed, the release of *H. silvanidis*, and the application of the pirate warehouse bug *Xylocoris flavipes* (Reuter). The bethylid wasp *H. silvanidis* is an ectoparasitoid of larvae of *Tribolium confusum* Jacquelin du Val 1868, eventually it is even monophagous on this beetle. Some life-history data on the biology of *H. silvanidis* is available. Recently Frielitz (2007) found that female *H. silvanidis* are comparatively long-lived if provided with honey as a food source (Fig. 4). Even if no hosts are present (or found), at 25-26°C females live 51 d. Other parasitoids of stored-product pests typically live for 4 to 14 d at this temperature (Eliopoulos, 2007). Extended longevity is a promising trait because foraging is not time-limited in situations of low pest densities, e.g. after a heat treatment. The honey can easily be provided within the release unit. There is little information on host-finding behaviour, and this information is crucial for successful application for biological control. Lorenz et al. (2010) showed that female *H. sylvanidis* attacked *T. confusum* larvae down to 4 cm depth in fine grist (main particle size: < 0.2 mm) and down to at least 8 cm depth in coarse grist (main particle size: 1.4 - 3mm).

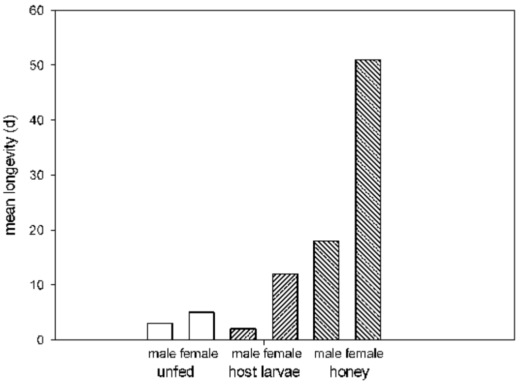

Figure 4 Longevity of *Holepyris silvanidis* at different nutritional conditions at 25-26°C and 55 ± 2.5 % r.h. (from Frielitz, 2007).

The pirate warehouse bug *X. flavipes* is a polyphagous predator of eggs and early developmental stages of many stored-product pests. *Xylocoris flavipes* can suppress *T. confusum* in presence of a thin flour layer or small amounts of flour (Schöller and Prozell, 2010), a result that was not expected because LeCato (1974) found no suppression in bulk wheat flour on *T. confusum,* even though the beetles were completely controlled in rolled oats and whole wheat, and partially in cracked maize. In bakeries and mills, flour is not only present in bulk in silos or in bags, but thin flour layers can be found in processing areas and flour residues accumulate in cracks or little heaps. In such places, *T. confusum* can frequently be found and would be the target of foraging *X. flavipes*.

4. Biological control of museum and structural pests

Stored-product pests may destroy materials as well, either on their way to pupation sites or because the materials contain ingredients suitable for development. In Halle / Saale, Saxony-Anhalt, Germany, a historic library became infested by *Stegobium paniceum* (L.). The beetles were thriving both below the floorboard on wheat straw used as insulation, and in book covers. The books originated from the 16th to 18th century, when the book covers were filled with pulp made from linen scraps. *Stegobium paniceum* developed in the pulp, produced the characteristic exit holes and therewith destroyed irreplaceable cultural heritage (Fig. 5). The books were moved to a fumigation-chamber and treated with nitrogen. However, some re-infestation was detected after the books were moved back to the library, presumably originating from the floorboard. The parasitoid *L. distinguendus* was released on the shelves, 2000 in October and 2000 in June. The release was evaluated to have successfully suppressed the re-infestation of the library. Another trial on host-finding in boxes containing books was carried out in an Israeli library, where *L. distinguendus* was shown to find host larvae both between and inside infested books (Wilamowski et. al., 2008).

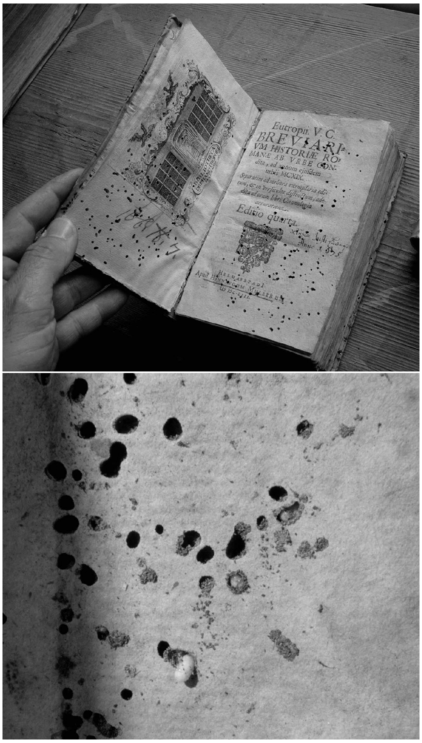

Figure 5 Book from the 17th Century infested by the drugstore beetle *Stegobium paniceum* (top), detail with larvae (bottom).

Lariophagus distinguendus has also been released to control the hump beetle *Gibbium psylloides* (Czenpinski) and the golden spider beetle *Niptus hololeucus* (Faldermann) in historic buildings in Germany. These beetles infest the fillings made by plant material and mud. While the larvae develop hidden with in the walls and in dead floors, the beetles appear in the rooms, sometimes in large numbers. Field applications during the last three years were promising and will be continued (Kassel, 2008).

A number of laboratory and field studies addressed the biological control of the common furniture beetle *Anobium punctatum* (L.). The attempt to control *A. punctatum* with *L. distinguendus* failed: even though the larvae of *A. punctatum* were physiologically suitable as hosts for *L. distinguendus*, the parasitoids they were not able to reach the larvae within wood and/or had not enough space within the galleries for parasitisation (Steidle et al., 2007).

Early detection of material destroying pests is essential to prevent damage, especially when irreplaceable objects of cultural heritage are concerned. However, monitoring of these pest species is often difficult. For example, pheromone traps for detection of *A. punctatum* resulted in very poor trap catches in field trials in Germany. During the course of study of natural enemies, it turned out that some natural enemies are more easily detectable and give indirect evidence of the presence of the pest. Paul et al. (2007)

studied *A. punctatum* and its natural enemies in a church closed for restoration in Erfurt, Germany. Yellow dish traps, a monitoring technique used in outdoor ecological field studies was used here in the context of protection of museum artefacts and wood. Yellow dishes are filled with water and a bit of detergence in order to attract flower-visiting insects (Mühlenberg, 1989). These traps are especially attractive for parasitoids that do no host-feeding and rely on nectar for adult nutrition. Other arthropods are trapped by chance, the number caught in the trap is affected by the number of insects present and temperature. Table 1 shows the number of *A. punctatum* and three natural enemies trapped in yellow dish traps. Few *A. punctatum* were trapped, mostly between mid of June and mid of July. The braconid parasitoid *Spathius exarator* (L.) was trapped throughout the trapping season from mid of May to mid of July in relatively large numbers, the peak coinciding with that of *A. punctatum*. The presence of *A. punctatum* could therefore be proven before adult beetles became active. The bethylid parasitoid *Cephalonomia gallicola* Ashmead and the beetle predator *Korynetes caeruleus* (DeGeer) were trapped before *A. punctatum*, too, but numbers were too low to make them promising candidates for indirect monitoring for *A. punctatum*.

Table 1 *Anobium punctatum*, common furniture beetle and its parasites and predotors trapped in yellow dish traps in the Allerheiligen church in Erfurt, Germany, 2006.

Species	Insects trapped						
	Date of collection						
	May 19	**June 2**	**June 16**	**June 23**	**June 30**	**July 7**	**July 14**
Anobium punctatum	0	1	0	5	10	4	1
Spathius exarator	5	10	9	51	87	31	25
Korynetes caeruleus	4	0	4	0	1	0	0
Cephalonomia gallicola	2	4	3	2	1	1	1

A monitoring method currently used for *A. punctatum* is the count of frass piles composed of faecal pellets and fine wood fragments. The absence of new frass piles after injection of insecticides into the galleries of *A. punctatum* was previously thought to be an indicator of effective control of *A. punctatum*. However, Paul et al. (2007) showed that the frass piles are caused by the beetle predator *K. caeruleus* foraging for *A. punctatum*-larvae. The injection of chemical insecticides into gallery of *A. punctatum* consequently negatively affects the predator *K. caeruleus* and stops its digging activity, but did not control *A. punctatum* (Paul et al., 2007). In Germany, the predator was shown to be active all year round except for the coldest period around February in an unheated church (Fig. 6). Unfortunately, rearing of the predator for biological control seems to be too difficult due to the extended larval period and larval mortality at high temperatures (Haustein et al., 2010).

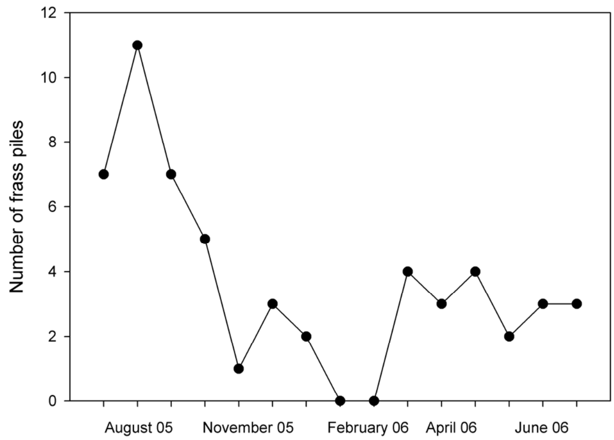

Figure 6 Frass heaps due to *Korynetes caeruleus* below a kneeler in the Allerheiligen-church in Erfurt, Germany (after Paul et al., 2007).

Several studies focused on the biological control of the webbing clothes moth *Tineola bisselliella* (Hummel) with the help of egg- and larval parasitoids (Plarre et al., 1999; Zimmermann et al., 2003). No mass-production technique has been developed yet for larval parasitoids, and efficiency of the mass-release of *Trichogramma* spp. has been variable. However, recent promising results have been obtained for the mass-release of *T. evanescens* in museums. Historic cars in museum exhibition rooms were treated in Vienna (Austria) and Munich and Bochum (Germany). Felt mats within the cars were infested by *T. bisselliella*. The surface area of felt is relatively small compared to other woolen materials, and monitoring of the moths with the help of pheromone-baited sticky traps showed a breakdown of the moth population after parasitoid release. The number of *T. evanescens* released per week on a total of 60 cars was 45,000 (Biebl, 2009).

These examples show that there are practical applications for inundative biological control strategies for pests in materials and museums that meet the requirements for low or zero tolerance of pests in these environments. The reaction of the staff to the release of wasps has been positive, and the cost has been competitive in the cases presented here. However, biological control of material destroying pests is in its very beginnings. More information on naturally occurring enemies of material destroying pests can be found in Becker (1954).

5. Commercial production of natural enemies

The release of *T. evanescens*, *H. hebetor*, *L. distinguendus* or *A. calandrae* and *C. tarsalis* has proven to be economically feasible for pest control companies. On the one hand, they can get new clients in the organic food market, on the other hand they can offer a wider range of control techniques and brand competence.

Natural enemies against stored-product pests are now produced in Germany, The Netherlands and Switzerland. Biological control is especially attractive to processing facilities that are not willing to stop production for pest control operations. Small farms with bulk grain stores that are not gas-tight apply parasitoids as well. For moth control in private households, internet shops sell *Trichogramma* sp. throughout Europe. The release units are sent several times to the consumer to cover at least eight weeks of parasitoid activity.

In a way, the application of natural enemies is an open-source-technology. Organisms cannot be patented, and hopefully this will be the case in the future. Registration is either not required for macro-organisms for biological control, or registration cost is comparatively low. Consequently, potentially every pest-control company can start the production of beneficials. Producers of beneficials may be more competitive by the development of innovative release units, the development of cost-effective rearing methods, or the development of rearing methods for beneficials that were hitherto not commercially produced. As long as beneficials do not become part of food, there are many opportunities to apply beneficials in stored-product environments.

6. Conclusions

Both non-chemical control methods for complete disinfestations and methods for suppression of re-infestation or residual infestations are needed. Specific control strategies have to be developed that provide rapid and effective suppression of pest populations. Even though non-chemical methods are currently widely applied, more examples are needed for cost-effective management methods that have been tested extensively under commercial conditions. An integrated management strategy is needed to keep products free from infestation along the whole storage chain from the raw products to the consumer. Biological control is a part of that strategy.

References

Adler, C., 2007. Improving the reliability of heat treatments in food industry. In: Navarro, S., Adler, C., Riudavets, J., Stejskal, V. (Eds), Integrated protection of stored products, IOBC WPRS Bulletin 30, 221-227.

Arbogast, R.T., 1984a. Biological control of stored-product insects: status and prospects. In: Baur, F.J. (Ed), Insect Management for Food Storage and Processing, American Association of Cereal Chemists, Inc., St. Paul, Minneapolis, USA pp. 225-238.

Arbogast, R.T., 1984b. Natural enemies as control agents for stored-product insects. In: Mills, R.B., Wright, V.F., Pedersen, J.R., McGaughey, W.H., Beeman, R.W., Kramer, K.J., Speirs, R.D., Storey, C.L. (Eds), Proceedings Third International Working Conference on Stored-Product Entomology, October 23-28, Kansas State University, Manhattan, Kansas, USA, pp. 360-374.

Becker, G., 1954. Räuber und Parasiten holzzerstörender Insekten in Gebäuden. Verhandlungen der Deutschen Gesellschaft für angewandte Entomologie 1954, 76-86.

Biebl, S., 2009. Deutsches Museum: Nützlinge gegen Kleidermotten. Der praktische Schädlingsbekämpfer 3/2009, 14-15.

Brower, J.H. 1990. Stored product pests, In: Habeck, D.H., Bennett, F.D., Frank, J.H. (Eds). Classical biological control in the southern United States. Southern States Cooperative Series Bulletin Number 355, pp. 113-122.

Brower, J.H., 1991. Biologicals: insect diseases, insect parasites, and predators. In: Krischik, V., Cuperus, G., Galliart, D. (Eds), Management of Grain, Bulk Commodities, and Bagged Products. USDA, Cooperative Extension Service, Circular E-912, Beltsville, USA, pp. 195-200.

Brower, J.H., Smith, L., Vail, P.V., and Flinn, P.W., 1996. Biological control. In: Subramanyam, B., and Hagstrum, D.W. (Eds), Integrated Management of Insects in Stored Products, Marcel Dekker, New York, USA, pp. 223-286.

Burkholder, W.E., 1981. Biological suppression of stored-product insect pests. In: Papavizas, G.C. (Ed) Biological Control in Crop Production. Beltsville Symposium on Agricultural Research (BARC), Allanheld, Osmun, Totowa. 5, 391-399.

Burkholder, W.E., Faustini, D.L., 1991. Biological methods of survey and control. In: Gorham, J.R. (Ed), Ecology and Management of Food Industry Pests. Food and Drug Administration Technical Bulletin, AOAC Press, 4, 361-372.

Burks, C.S., Johnson, J.A., Maier, D.E., Heaps, J.W., 2000. Temperature. In: Subramanyam, B., Hagstrum, D. W. (Eds) Alternatives to Pesticides in Stored Product IPM. Kluwer Academic Publishers, Boston, USA, pp. 73-104.

Calderon, M., Navarro, S., Donahaye, E., 1966. The effect of low pressures on the mortality of six stored-product insect species. Journal of Stored Products Research 2, 135-140.

Dosland, O., Subramanyam, B. Sheppard, K., Mahroof, R., 2006. Temperature modification for insect control. In: Heaps, J. W. (Ed) Insect Management for Food Storage and Processing. American Association of Cereal Chemists International, St. Paul, Minnesota, USA, pp. 89-103.

Eliopoulos, P.A., 2007. The importance of food supplement for parasitoids of stored product pests: the case of *Venturia canescens* (Hymenoptera: Ichneumonidae). In: Navarro, S., Adler, C., Riudavets, J., Stejskal, V. (Eds), Integrated protection of stored products, IOBC WPRS Bulletin 30, 37-41.

Fields, P.G., 1992. The control of stored product insects and mites with extreme temperatures. Journal of Stored Products Research 28, 89-118.

Fields, P.G., White, N.D.G., 2002. Alternatives to methyl bromide treatments for stored product and quarantine insects. Annual Review of Entomology 47, 331-359.

Frielitz, C., 2007. *Holepyris sylvanidis* , ein Parasitoid zur Bekämpfung der Larven des Amerikanischen Reismehlkäfers –Untersuchungen zur Morphologie, Biologie und Parasitierungsleistung. Diploma-Thesis, Institute for Applied Zoology, Free University Berlin, 58 pp.

Grieshop, M.J., Flinn, P.W., Nechols, J.R., Schöller, M., 2007. Host-foraging success of three species of *Trichogramma* in simulated retail environments. Journal of Economic Entomology 100, 591-598.

Haines, C.P., 1984. Biological methods for integrated control of insects and mites in tropical stored products: III The use of predators and parasites. Tropical Stored Product Information 48, 17-25.

Hansen, L.S., 2007. Potential for widespread application of biological control of stored- product pests – the European perspective. Journal of Stored Products Research 43, 312-313.

Hansen, L.S., Steenberg, T., 2007. Combining larval parasitoids and an entomopathogenic fungus for biological control of *Sitophilus granarius* (Coleoptera: Curculionidae) in stored grain. Biological Control 40, 237–242.

Hansen, L.S., Wakefield, M., 2007. European network on biological control of pests in stored products - COST Action 842, WG 4. In: Navarro, S., Adler, C., Riudavets, J., Stejskal, V. (Eds), Integrated protection of stored products, IOBC WPRS Bulletin 30, 21-23.

Haustein, T., Reichmuth, C., Laar, C. von, 2010. Nützlinge im Holzschutz. Verhandlungen der Holzschutztagung 2010 des Sächsischen Holzschutzverbandes e.V., March 13, Leipzig (in press).

Hofmeir, H., 2002. ThermoNox – heat treatment as a non-toxic pest control. In: Navarro, S., Adler, C., Riudavets, J., Stejskal, V. (Eds), Integrated Protection of Stored Products, IOBC WPRS Bulletin 25, 183-185.

Imholte TJ, Imholte-Tauscher TK. 1999. Engineering for Food Safety and Sanitation. Technical Instutition for Food Safety, Woodinville, USA.

Kassel, A., 2008. Im Würgegriff. Biologische Schädlingsbekämpfung bei Messingkäfer- und Kugelkäfer-Befall. B+B Bauen im Bestand 31, 42-43.

LeCato, G.L., 1974. Habitat-influencing predation by *Xylocoris flavipes* (Reuter) (Hemiptera: Anthocoridae). The American Midland Naturalist 93, 510-512.

Lorenz, S., Adler, C., Reichmuth, C., 2010. Penetration ability of *Holepyris sylvanidis* into the feeding substrate of its host *Tribolium confusum.* In: Carvalho, O.M, Fields, P.G., Adler, C.S., Arthur, F.H., Athanassiou, C.G., Campbell, J.F., Fleurat-Lessard, F., Flinn, P.W., Hodges, R.J., Isikber, A.A. Navarro, S., Noyes, R.T., Riudavets, J., Sinha, K.K., Thorpe, G.R., Timlick, B.H., Trematerra, P., White, N.D.G. (Eds), Proceedings of the Tenth International Working Conference of Stored Product Protection, 27 June-2 July 2010, Estoril, Portugal, Julius-Kühn Archives, Berlin, Germany, in press.

Mbata, G.N., Phillips, T.W., Payton, M., 2004. Mortality of eggs of stored-product insects held under vacuum: Effects of pressure, temperature, and exposure time. Journal of Economic Entomology 97, 695-702.

Mühlenberg, M., 1989. Freilandökologie. UTB, Quelle and Meyer, Heidelberg, Germany.

Mullen, M.A., Pederson, J.R., 2000. Sanitation and exclusion. In: Subramanyam, B., Hagstrum, D. W. (Eds), Alternatives to Pesticides in Stored Product IPM. Kluwer Academic Publishers, Boston, USA, pp. 29-50.

Niedermayer, S., Steidle, J.L.M., 2007. Influence of extreme temperatures in grain stores on the parasitation ability of beneficial insects in stored product protection. 9. Wissenschaftstagung Ökologischer Landbau, http://orgprints.org/ view/ projects/wissenschaftstagung-2007.html; http://orgprints.org/9631/.

Nilakhe, S.S., Parker, R.D., 1990. Implementation of parasites and predators for control of stored-product pests. Proceedings of the third National Stored Grain Pest Management Training Conference, Kansas City, Missouri, October 20-25, 1990, pp. 241-250.

Paul, F., Prozell, S., Schöller, M., 2008. Monitoring natürlicher Feinde des Gemeinen Nagekäfers *Anobium punctatum* (DeGeer, 1774) (Coleoptera: Anobiidae). Mitteilungen der Deutschen Gesellschaft für Allgemeine und Angewandte Entomologie 16, 323-326.

Plarre, R., Lieber, K., Burkholder, W., Phillips, J., 1999. Host and host instar preference of *Apanteles carpatus* (Say) (Hymenoptera: Braconidae) a possible parasitoid for biological control of clothes moths (Lepidoptera: Tineidae). Journal of Stored Products Research 35, 197-213.

Plarre, R., Reichmuth, F., 2000. Impact. In: Subramanyam, B., Hagstrum, D. W. (Eds), Alternatives to Pesticides in Stored-Product IPM. Kluwer Academic Publishers, Boston, USA, pp. 401-417.

Prozell, S., Schöller, M., 2004. Efficacy of vacuum and saturated water steam on stored-product moths and beetles. In: Navarro, S., Adler, C., Schöller, M., Emekçi, M., Ferizli, A. G. and Stengård Hansen, L. (Eds), Integrated Protection of Stored Products. Proceedings of the Meeting at Kuşadasi (Turkey), September 16-19, 2003. IOBC WPRS Bulletin 27, 257-260.

Reed, C., Arthur, F.H., 2000. Aeration. In: Subramanyam, B., Hagstrum, D. W.Eds), Alternatives to Pesticides in Stored Product IPM. Kluwer Academic Publishers, Boston, USA, pp. 51-72.

Schöller, M., 1998. Integration of biological and non-biological methods for controlling arthropods infesting stored products. Postharvest News and Information 9, 15N-20N.

Schöller, M., Flinn, P. W., 2000. Parasitoids and predators. In: Subramanyam, B., Hagstrum, D. W. (Eds), Alternatives to Pesticides in Stored Product IPM. Kluwer Academic Publishers, Boston, USA, pp. 229-271.

Schöller, M., Flinn, P.W., Grieshop, M.J., Zdarkova, E., 2006. Biological control of stored product pests. In: Heaps, J. W. (Ed) Insect Management for Food storage and Processing. American Association of Cereal Chemists International, St. Paul, Minnesota, USA, pp. 67-87.

Schöller, M., Prozell, S., 2006. Natural enemies to control stored product pests in grain stores and retail stores. In: Stengård Hansen, L., Enkegaard, A., Steenberg, T., Ravnskov, S., Larsen, J. (Eds), Implementation of Biocontrol in Practice in Temperate Regions – Present and Near Future. DIAS report No. 119, 85-106.

Schöller, M. and Prozell, S., 2007. Nützlinge für die Leeraumbehandlung im Vorratsschutz. Pest Control News 35, 12-13.

Schöller, M., Prozell, S., 2010. Potential of *Xylocoris flavipes* (Hemiptera: Anthocoridae) to control *Tribolium confusum* (Coleoptera: Tenebrionidae) in Central Europe. IOBC/WPRS Bulletin (in press).

Schöller, M., Prozell, S., Al-Kirshi, A.-G., Reichmuth, Ch., 1997. Towards biological control as a major component of integrated pest management in stored product protection. Journal of Stored Products Research 33, 81-97.

Steidle, J.L.M., Gantert, C., Noldt, U., Prozell, S., Schöller, M. 2007. Bekämpfung von holzzerstörenden Käfern durch Massenfreilassungen der Lagererzwespe: Fiktion und Fakten. pp. 163-172. In: Noldt, U., Michels, H. (Eds) Holzschädlinge im Fokus. Alternative Maßnahmen zur Erhaltung historischer Gebäude. Schriften des LWL-Freilichtmuseums Detmold, Westfälisches Landesmuseum für Volkskunde, vol. 27, Detmold.

Steidle, J.L.M., Schöller, M., 2001. Fecundity and ability of the parasitoid *Lariophagus distinguendus* (Hymenoptera: Pteromalidae) to parasitize larvae of the granary weevil *Sitophilus granarius* (Coleoptera: Curculionidae) in bulk grain. Journal of Stored Products Research 38, 43-53.

Wilamowski, A., Kessler, I., Rabin, I., Prozell, S., Navarro, S., 2008. Biological control of *Anobium punctatum* in infested books, using the parasitoid *Lariophagus distinguendus*. Ninth International Conference on NDT of Art, Jerusalem Israel, 25-30 May 2008, http://www.ndt.net/article/art2008/papers/232Wilamowski.pdf

Wyss, U., Schöller, M., Prozell, S., 2007. Die Mehlmotte und ihr natürlicher Feind *Habrobracon hebetor*. DVD-Video, 11 min, http://www.entofilm.com.

Zimmermann, O, Schöller, M., Prozell, S., 2003. The use of *Apanteles carpatus* (Hymenoptera: Braconidae) and *Trichogramma* spp. (Hymenoptera: Trichogrammatidae) for biological control of tineid moths (Lepidoptera). In: Credland, P.F., Armitage, D.M., Bell, C.H., Cogan, P.M., Highley, E. (Eds), Advances in Stored Product Protection. Proceedings of the Eighth International Working Conference on Stored Product Protection, 22.-26. July 2002, York, United Kingdom, pp. 319-321.