

favorable and even at unfavorable temperature conditions of June-August. The presence of warm weather wasp-strains may suggest the existence of well-adapted wasp species or strains which may be appropriate candidates for the control of stored product pests. The strains had also been collected in late winter and summer, thus demonstrating activity also during less favorable weather conditions, raising again the possibility of using these egg parasitoids as an inundative biological control agent in stored products.

Experiments were carried out by offering eggs of the Indianmeal moth *Plodia interpunctella* (Hübner), the Mediterranean flour moth *Ephesia kuehniella* Zeller, the warehouse moth *E. elutella* (Hübner), and the almond moth *Cadra cautella* (Walker) in choice and no-choice assays to a single female parasitoid. Two different choice experiments were used to certify the same conclusion in both methods. The bioassay for host-preference of *Trichogramma* spp. was carried out by offering a single female wasp the choice between equal numbers of host eggs on square cards "Petri dish tests" and /or strip cards "strip card tests". In both methods, counting the number of *Trichogramma* developing in the host eggs (parasitism) show the preference of the wasp for ovipositing and indicated the ability of the parasitoid to develop in these eggs (i.e., host suitability).

In Petri dish tests, *E. kuehniella* was a highly accepted host species for *T. bourarachae*, *T. euproctidis*, and *T. cacociae* wasps while *E. elutella* and *C. cautella* eggs were more accepted by *T. evanescens* and *T. cordubensis*, respectively. In the strip card tests, *E. kuehniella* eggs were highly accepted by *T. bourarachae*, *T. cacociae* and *T. evanescens*. Eggs of *E. elutella* and *C. cautella* were more acceptable for *T. euproctidis* and *T. cordubensis*, respectively. Furthermore, a comparative study of the parasitic capacity of the *Trichogramma* spp. was carried out under 'no choice conditions' by exposing a freshly emerged single wasp to an unlimited number of host eggs. Significant differences were found among the parasitic capacity of the tested *Trichogramma* spp.: *T. bourarachae* showed a good parasitic potential against *S. cerealella* and *E. kuehniella*; *T. evanescens* and *T. cacociae* against *S. cerealella*; *T. cordubensis* against *S. cerealella* and *P. interpunctella* and *T. euproctidis* against *P. interpunctella*. However, dissection of host eggs with wasp-emergence holes showed that all tested wasps had a propensity to superparasitize the host eggs. Results of the present work suggest that the test wasps failed to discriminate parasitized hosts eggs among a large number of non-parasitized eggs, thus superparasitism occurred. Also, both of Petri dish and strip cards methods may underestimate the actual parasitization capacity due to self-superparasitism and mortality in black eggs that suffered desiccation during the early stages.

T. cordubensis, *T. euproctidis* and *T. bourarachae* showed promise for further investigation into selecting new biological control agents against some stored product lepidopterous pests.

Keywords: Stored product moths; *Trichogramma* spp.; host preference; parasitization capacity; superparasitism.

Monitoring of the Indian meal moth and its parasitoids in long-term grain storage

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Abstract

The Indian meal moth *Plodia interpunctella* became a major pest in bulk grain storage in Germany in recent years. Monitoring with adhesive pheromone-baited traps revealed a dependence of the number of generations of the moth from the temperature conditions in store, which themselves depend on insulation of the storage structure. The larval parasitoid *Habrobracon hebetor* was monitored with the help of cone traps placed in the grain. Baiting these traps with moth webbing significantly increased the number of female wasps trapped in 5 cm depth in wheat. Field trials showed both the pest and the beneficial can be monitored in stores, but more research is needed to develop a biological control strategy for *P. interpunctella*.

Keywords: stored products, bulk grain, Pyralidae, Trichogrammatidae, Braconidae

Introduction

Monitoring of pest populations is a basic prerequisite for biological control of stored-product pests (Zimmermann 2004), but difficult in large quantities of bulk grain. Within the frame of a project on the application of beneficials in long-term grain storage of grain, the phenology of the Indian meal moth *Plodia interpunctella* (Hübner, 1813) (Lepidoptera, Pyralidae) was studied in different grain flat

stores. In German grain storage, large populations of the Indian meal moth were observed in the past six years resulting in significant damage and repeated control activities, consequently new control options were evaluated. The Indian meal moth is laying up to 400 eggs close to the stored product. The emerging larvae typically develop through five instars in grain. A first signal of infestation are webbings on the grain surface produced by the larvae, produced presumably for protection. The last larval instar shows increased mobility in order to find a pupation site, and is consequently called wandering larva (Mohandass et al., 2007).

For the development of a biological control strategy a monitoring of the beneficials is helpful. The larval parasitoid *Habrobracon hebetor* (Say, 1836) is naturally occurring in Central Europe, among its hosts are the Indian meal moth, the warehouse moth *Ephestia elutella* (Hübner, 1796) and the flour moth *E. kuehniella* Zeller, 1879 (Prozell & Schöller 2001).

In this study, the effectiveness of different monitoring techniques for parasitoids is described and the potential release of beneficials within the frame of an integrated control concept discussed.

Materials and Methods

Monitoring of the Indian meal moth *P. interpunctella*: The phenology was studied in different flat grain stores. Various methods were applied, i.e. adhesive surfaces for larvae and adults, artificial pupation aid structures for larvae, and pheromone-baited traps for adults (Fig. 1).

Monitoring of the larval parasitoid *H. hebetor*: 20 kg grain, wheat or oats, respectively, were filled in a Hobbock. Per Hobbock, one cone trap was placed (Fig. 1). The cone trap has two components, a vial and a perforated lid. The lid is regularly vaulted, this is where the insect enter. The diameter of the holes in the lid is approximately 2 mm. Liquid teflon is added to the upper rim of the vial, in order to hinder the insects to move back to the lid. The cone trap was placed either on the grain surface, or 5 cm deep in the grain. The cone traps on the surface were carefully placed in one level with the grain surface. The cone traps were either unbaited, or baited with 5 g of webbings of the flour moth. Per Hobbock, 50 *H. hebetor* were released, i.e. 25 females and 25 males. The Hobbocks were closed and stored for 14 days at $20.8^{\circ}\text{C} \pm 0.95^{\circ}\text{C}$ (mean \pm SD) and $43.6\% \pm 5.5\%$ RH (mean \pm SD). After that period, the cone traps were removed and the trapped *H. hebetor* counted. The sex ratio of *H. hebetor* was determined. Moreover, six cone traps each were placed in different grain flat stores (3000–4000 metric tons wheat) and removed ca. four weeks after parasitoid release, again the number of insects trapped was counted.

The number of trapped insects were compared with the help of a t-test, in case data were not normally distributed, the Mann-Whitney Rank Sum Test was applied. Statistical analyses were performed using the software package SigmaStat 3.1.



Fig. 1 Cone trap used for monitoring of *Habrobracon hebetor* (a) and adhesive trap baited with sex pheromone (ZE-TDA) (b) for monitoring of *Plodia interpunctella* in flat grain storage.

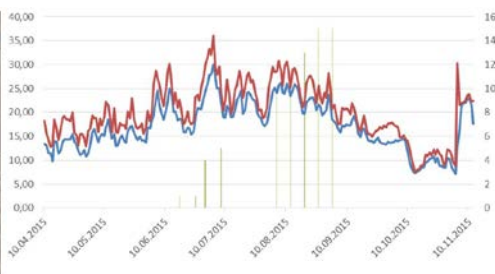


Fig. 2 Records of adult *Plodia interpunctella* (green bars) in a non-isolated store in Northern Germany, 2015. Left axis: surface temperature [°C], right axis: no. of moths. Blue line: mean temperature, red line: maximum temperature.

Results

Monitoring of *P. interpunctella*: In a non-isolated storage building in Northern Germany, adult moths were recorded already in June, 2015 (Fig. 2), while in a well isolated storage building in Southern Germany, adult moth activity started in August (Fig. 3). At that time, a second generation of adults developed already in the non-isolated store (Fig. 2). A peak in the number of adult moths in the non-isolated store was reached in August.

While the F₂-moth progeny in the non-isolated store overwintered in the last larval instar, only one moth generation was recorded in the well-isolated grain store (Fig. 3).

Monitoring of *Habrobracon hebetor*:

(1) Unbaited cone traps: both in wheat (t-Test, t = 8.061, DG=4, P<0.001) and in oats (t-Test, t = 8.061, DG=4, P<0.001), significantly more wasps were trapped in 0 cm compared to 5 cm depth (Fig. 4). On the surface, significantly more wasps were trapped in wheat compared to oats (t-Test, t = -3.742, DG=4, P = 0.020). In 5 cm depth, no difference in recapture was detected comparing wheat and Oats (t-Test, t = -0.707, DG=4, P > 0.05).

(2) Baited cone traps: baited with webbings, cone traps on the surface, caught more wasps in oats compared to such unbaited traps on the surface (t-Test, t = -8.721, DG=4, P <0.001) (Fig. 4). In wheat, baited traps caught on the surface a larger number of wasps, however, this difference was not significant (t-Test, t = 2.286, DG=4, P = 0.084).

Baited traps placed in 5 cm depth in wheat caught more wasps compared to unbaited traps (t-Test, t = -3.530, DG=4, P = 0.024). In oats, no difference in wasps caught in traps placed in 5 cm depth was detected whether the traps were baited with webbings or not (t-Test, t = -1.444, DG=4, P = 0.222). More female wasps were caught in total with baits (t-Test, t = -2.119, DG=22, P = 0.046), but the presence of webbings as bait did not increased the number of males trapped (Mann-Whitney Rank Sum Test, T = 125.5, n=12, P = 0.163).



Fig. 3 Records of adult *Plodia interpunctella* (red bars) in a well-isolated grain store in Southern Germany in 2015. Left axis: surface temperature [°C], right axis: no. of moths. Blue line: mean temperature, green line: maximum temperature.

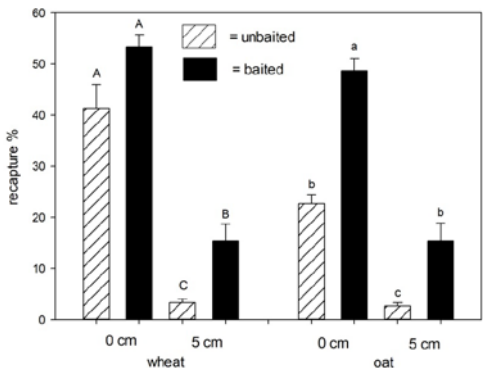


Fig. 4 Recapture of *Habrobracon hebetor* with the help of cone traps in percent, with or without 5 g webbings of *Ephestia kuehniella* as bait in wheat or oats. 50 *H. hebetor* (males and females) released. Different caps indicate significantly different recapture, major caps for wheat, small caps for oats (p<0.05).

Discussion

Under field conditions, pupation of moth larvae and the start of flight of the adult Indian meal moths in spring are mainly depending on temperature in the store. While in a non-isolated store the progeny of the second generation overwintered as larvae, in an isolated cooler store only one generation was observed annually. These observations under practical conditions are well explainable by the developmental time known from laboratory data (Mohandass et al., 2007).

The attractiveness of moth webbing in the cone traps placed in grain on the females confirms olfactometer laboratory trials showing kairomonal activity of webbing produced by different species of pyralid Lepidoptera for *H. hebetor* (Strand et al. 1989). Moreover, foraging *H. hebetor* were shown to enter into bulk grain in previous studies (Schöller, 2000). In the present study, female *H. hebetor* were shown to exploit signals from moth webbing in bulk grain, too. Consequently, parasitisation of Indian meal moth larvae can be expected below the grain surface, too. This behaviour of *H. hebetor* can also be used to monitor the foraging behaviour of the wasps under practical conditions of storage. In wheat, more *H. hebetor* were trapped compared to oats. This might be due to the three-dimensional structure of the bulk grain.

Both male and female *H. hebetor* were caught with the cone traps. The capture of females in unbaited traps indicates this trap type is able to record passively the movement activity of the parasitoids. Males could potentially be attracted by already caught females, however, in our trials, a significantly higher number of females in the baited traps did not result in a significant increase in the number of males caught.

The results on monitoring showed the possibility to record data on the phenology of the Indian meal moth and *H. hebetor* under practical field conditions. The abiotic conditions in different grain stores are subject to wide variation, consequently more field trials are needed in order to develop recommendations for biological control of the Indian meal moth.

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A preliminary study of growth and development of *Cheyletus malaccensis* (Oudemans) under different humidity conditions

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Abstract

Cheyletus malaccensis (Oudemans) is a species of predatory mite, which is widely distributed in grain storage, and is a potential natural enemy of stored-product pests. Based on the typical temperatures and humidities that occur in granaries, the growth and development of *C. malaccensis* was studied at 24°C with different relative humidities (RH 65±2%, 75±2%, 85±2% and 95±2%). During this study, *C. malaccensis* was fed on *Acarus siro* (Linnaeus), a very important stored grain pest to investigate its potential to control this pest and production of this natural enemy in the laboratory. The results showed that *C. malaccensis* has five developmental stages, egg, larva, protonymph, deutonymph and adult. The deutonymph stage is absent in males. For females, the developmental time from egg to adult was shortest at 85±2 % RH and averaged 16.3 days; developmental time was longest at 65±2 % RH and averaged 18.6 days. The male mites in the 95±2% RH trials had the shortest developmental time which averaged 12.6 days; it was longest at 65±2% RH where it averaged 14.7 days. At 95±2