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Trapping of Internal and External Feeding Stored Grain Beetle Pests with Two Types of Pitfall Traps: a Two-year Field Study

Radek AULICKY, Vaclav STEJSKAL, Zuzana KUCEROVA and Pascale TREMATERRA

[1]Department of Stored-Product Pest Control, Division of Crop Protection and Plant Health, Crop Research Institute, Prague, Czech Republic; [2]Department of Agriculture, Environmental and Food Sciences, University of Molise, Campobasso, Italy.

Abstract

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Pitfall trapping studies are available for particular stored grain pest species. In small farms, the stored grain pest control strategy is rarely species-specific but is often "pest ecological-group-specific" instead. A two-year field study was conducted in flat grain stores to compare the efficacy of cone-surface (PC trap; AgriSense-BCS Ltd., Pontypridd, UK) and probe-subsurface (WB Probe II Trap; Trécé Inc., Adair, USA) traps for three ecological insect pest groups (Group I, internal feeding primary pests; Group II, external feeding primary pests; Group III, external feeding secondary pests). Altogether, 1328 specimens (32% Group I, 11% Group II, and 57% Group III) in 12 species of Coleoptera (17% Group I, 25% Group II, and 58% Group III) were trapped. No significant differences were found in the efficacy of PC traps and WB Probe II Traps to catch the evaluated ecological pest groups over the long term. Our study indicated that for trends to appear in long-term trapping there was no need for the simultaneous use of both traps due to the low trapping differences between the surface and subsurface types of traps in all ecological pest groups. However, significant differences between the traps were found in the short-term evaluations and before and after fumigation; in that case, the use of both traps is recommended because of the higher sensitivity and more precise evaluation of efficacy of the control treatment effects.

Keywords: Coleoptera; stored-product pests; grain; stores; monitoring; ecology; integrated pest management; IPM; traps

Low tolerance of grain to storage and urban pests requires the development and implementation of monitoring methods that are sensitive enough to detect early pest infestation to prevent quality and economic losses (Trematerra 2013). In grain stores, multiple species infestations are common (Athanasiou *et al*. 2001; Stejskal & Hubert 2008; Hubert *et al*. 2009; Stejskal *et al*. 2014, 2015). Populations show various seasonal population dynamics and patterns (Arthur *et al*. 2014). When a population exceeds an economic threshold, a farmer/store keeper begins control intervention. The advanced decision-making pest control process based on "species-specific monitoring" and modelling is profitable for large grain elevators (Adama *et al*. 2010), whereas such complex systems are difficult to operate for small and middle-sized farmers because such farmers are usually not willing to discriminate all of the insect species that are present. Farmers mainly distinguish internal feeding pests (i.e. *Sitophilus* spp. or *Rhyzopertha dominica* (F.)) from external feeding pests (Table 1) because grain infested by internal feeding primary pest is refused or penalised by mills and commodity traders; these pests are the main source of fragments in processed flour (Trematerra *et al*. 2011). Therefore, in many cases, farmers fumigate only when primary internal feeding pests are present (e.g. Stejskal & Hubert 2008), whereas in the case of external feeding pests, they just clean them out using sieves and aspirators (Armitage 1994; Trematerra & Throne 2012).

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We believe that pest monitoring also should reflect the point of view of small farmers based on the pest-group control decision-making process. What traps and instructions for monitoring various groups of grain pests are currently available for farmers? Regarding pest monitoring, farmers usually start with the initial search for the most powerful trap for the target pest and then follow with an enquiry of the price and operational demands. In the case of stored grain traps, the decision is quite simple. There are basically two different types of pitfall traps (reported as cone surface traps and subsurface probe traps) to monitor beetles in stored grain.

However, information concerning the trap use and efficacy is quite complex and sometimes contradictory, which makes it difficult to understand and implement into practice by farmers (Cuperus *et al.* 1990). The species-specific differential efficacy of surface and subsurface pitfall traps has been documented (e.g. Hagstrum *et al.* 1998; Trematerra 1998; Weston & Barney 1998; Buchelos & Athanassiou 1999; Hagstrum 2000; Carvalho *et al.* 2004; Toews *et al.* 2005; Wakefield & Cogan 2007; Stejskal *et al.* 2008).

However, no study comparing the cone and probe trap efficacy between groups of internal and external feeding storage insect pests has been conducted, though the decision making process for small farmers is based on the discrimination of not particular pest species, but rather of an ecological group of pests. In addition, most studies are based on short-term experiments (several months), although Schirmel *et al.* (2010) have recently reiterated that the period of trapping may dramatically affect the capture of insects into pitfall ground traps.

In this work, we used the perspective of small farmers to explore how internal and external feeding primary and secondary insect pests react to two basic shapes of pitfall traps (PC trap and WB Probe II Trap) under field conditions, as represented by flat grain stores in long-term storage (for approximately 2 years). We were specifically interested in whether both traps are equally efficient in the reflection of pest groups and spectra that were present.

MATERIAL AND METHODS

Experimental site. The research was conducted in a flat grain store (hangar) in Central Bohemia (Czech Republic). The occurrence of pests in grain mass (wheat) using two different types of traps was analysed in this experiment. Monitoring was performed under normal working arrangements in a grain hangar during the two-year period (from October 2001 to December 2003). The Crop Research Institute has been running several long term monitoring experiments at various stores on the area of Central Bohemia. We selected the particular data set from 2001–2003, since it enabled us to perform a relatively long-term comparison of the tested types of traps. The grain store (56 × 17 m) had a double-wall construction, concrete bedding and floor, and was equipped with active aeration with ambient air. The outer wall was made of corrugated metal plates, and the inner wall was made of wooden boards.

Trap description. Commercial pitfall traps – PC traps (AgriSense-BCS Ltd., Pontypridd, UK) and WB Probe II Traps (Trécé Inc., Adair, USA) – were tested. The PC trap is a cone-shaped trap with a top surface that has holes for insect entry, and the trapping area is on a horizontal plane; the WB Probe II Trap is a rod for inserting deep in the grain, and the trapping area is in a vertical plane.

Trapping design. Nine trap points (e.g. 3 points in 3 rows) were established on the surface of grain mass (ca. 1000 t; rate 1 trap per ca. 111 t of grain) to cover the monitoring area (20 × 30 m). Two types of traps (PC trap and WB trap) were situated at every trap point. Traps were designed to capture crawling beetles on the surface (PC trap) and in the upper 50-cm layer (WB Probe II Trap). The first set of traps was placed in October 2001. The traps were then checked and emptied after 1 month of exposure, except for the terms when the store was without grain (from June 15 to September 12, 2002, and from January 22 to August 30, 2003) (Figure 1).

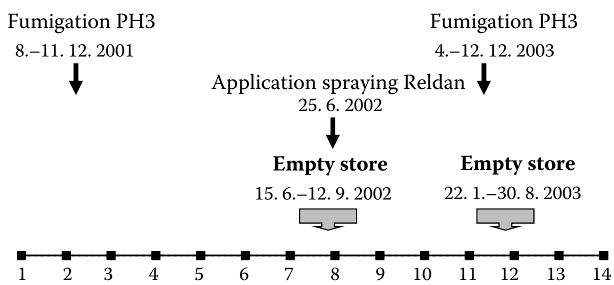

Figure 1. Calendar dates of periods of empty store and three chemical treatments (2× fumigation and 1× residual spray of empty store) occurring in the store in relation to particular capture events 1–14 (capture events 1–14 were from October 2001 to December 2003 – capture events 1–3 were in 2001, 4–12 in 2002, and 13–14 in 2003)

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Table 1. Classification of three main ecological-economical pest groups that were associated with stored grain

Pest group	Definition
Group I Primary internal feeding pests	A group of pests that is able to infest sound grain; larval development occurs inside of infested grain kernels
Group II Primary external feeding pests	A group of pests that are able to infest sound grain; larval development occurs mainly outside of the infested grain kernels
Group III Secondary external feeding pests	A group of pests that are not able to infest sound grain, mainly feeding on grain dust mixed with fungi or dead insect bodies; larval development occurs almost exclusively outside of the infested grain kernels

The content of altogether 252 traps was analysed in the laboratory. The traps were separately examined, and the trapped beetles were identified and counted.

Temperature measurements. The environmental temperature outside the store and the temperature inside the grains at a depth of 1 m at the time of particular capture events were measured (Figure 2).

Statistical evaluation. Comparisons of the trapping efficacy of the two types of traps (PC traps and WB traps) according to three ecological groups of pests were processed using a non-parametric Wilcoxon rank test (Statistica Version 12).

Definition of ecological pest groups. Three ecological groups of insect pests that were associated with stored grain were determined: Group I, Group II, and Group III (Table 1). Group I, the primary internal feeding pests, usually complete development within a single kernel of grain. Ovipositing females may lay each egg in a hole, that they have bored into the kernel and then seal the hole with a gelatinous plug, as do *Sitophilus* spp., or they may place the eggs outside the kernels, as do *Rhyzopertha dominica* (F.) and *Sitotroga cerealella* (Olvier). In the latter case, the first instar larvae burrows into kernels. Internal feeders are primarily a problem in grain fields or in grain storage and processing facilities. Group II,

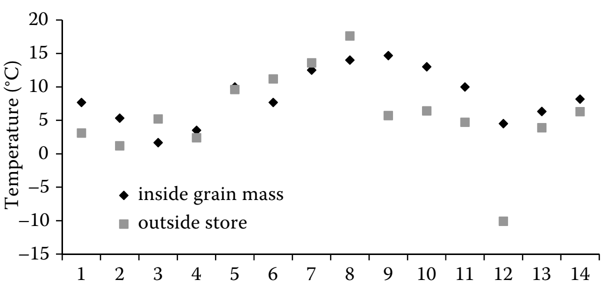

Figure 2. Mean temperature outside store and inside the grains at a depth of 1 m at the time of particular capture events 1–14 (capture events 1–14 were from October 2001 to December 2003 – capture events 1–3 were in 2001, 4–12 in 2002, and 13–14 in 2003)

primary external feeding pests, develop outside the kernels. These pests can feed on undamaged (starting by the germ) or damaged grain kernels, grain debris and grain products, and are often found in grain storages, processing plants, retail stores, and homes. Group III, secondary external feeding pests, are unable to penetrate or feed on undamaged grain kernels. These pests lay their eggs outside the kernels, and the larvae feed on dust and particles of food products or on kernels that have been damaged by internal or external feeders (Table 1).

RESULTS

Table 2 shows the list of beetles ranked according to ecological groups and their pooled captures for all of the trapping periods and frequencies in PC traps and WB traps. The cumulative numbers of particular species that were captured in both traps are presented in Figure 2. Altogether, 12 species of Coleoptera in 1328 specimens were found in both types of traps during the monitored period (46% in PC traps and 54% in WB Probe II Traps). The five predominant species that were captured were *Sitophilus granarius* (L.), *Oryzaephilus surinamensis* (L.), *Typhaea stercorea* (L.), *Lathridius minutus* (L.), and *Ptinus fur* L. (Figure 3). During the first months, *S. granarius* was the dominant species, comprising 79% of all of the beetles that were caught in the traps (Table 2). Next year, this species occurrence declined by 2% of the total, and *O. surinamensis*, *L. minutus*, and *T. stercorea* predominated. During the final year, the total numbers of three of these four species declined, but not *T. stercorea*, which was still the primary species that was caught in the traps (Figures 4–6). Few or no beetles of any species were trapped in January in any year, most likely because of the lower temperatures inside the warehouse, particularly inside the grains during that time. Group I primary pests (*R. domi-*

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Table 2. Abundance (N) and frequency (F) of stored-product beetles in a cone-surface PC trap and probe-subsurface WB Probe II Trap (WB) and their classification into particular ecological Groups I–III

	PC trap		WB Probe II Trap	
	N	F (%)	N	F (%)
Primary internal feeding pests (Group I)	**201**		218	
Rhyzopertha dominica (Fabricius)	1	7	1	7
Sitophilus granarius (Linnaeus)	200	79	217	71
Primary external feeding pests (Group II)	58		89	
Cryptolestes ferrugineus (Stephens)	6	14	23	29
Oryzaephilus surinamensis (Linnaeus)	42	64	60	71
Tribolium castaneum (Herbst)	10	21	6	21
Secondary external feeding pests (Group III)	342		420	
Ahasverus advena (Waltl)	35	43	55	36
Anthicus floralis (Linnaeus)	0	0	1	7
Anthrenus scrophulariae (Linnaeus)	1	7	0	0
Cryptophagus sp. Herbst	1	7	0	0
Lathridius minutus (Linnaeus)	205	79	80	50
Ptinus fur Linnaeus	18	50	125	57
Typhaea stercorea (Linnaeus)	82	43	159	29

nica and *S. granarius*) and Group II primary pests (*Cryptolestes ferrugineus* (Stephens), *O. surinamensis,* and *Tribolium castaneum* (Herbst)) constituted, respectively, 42 and 43% of all of the monitored species in both types of traps. Group III secondary pests (*Ahasverus advena* (Waltl), *Anthicus floralis* (L.), *Anthrenus scrophulariae* (L.), *Cryptophagus* sp., *L. minutus, Ptinus fur* and *T. stercorea)* constituted, respectively, 58 and 57% of all of the specimens that were captured in the two types of traps (Table 2). Overall, nine species were captured in both types of traps, whereas three species were captured only in PC traps (*A. scrophulariae* and *Cryptophagus* sp.) or in WB traps (*A. floralis*) (Table 2).

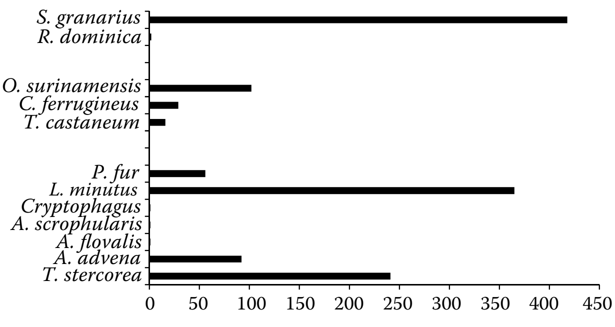

Figure 3. Cumulative number of individuals of insects pests (Group I, Group II, and Group III) captured with two types of traps (PC and WB Probe II traps) showing their dominance in the studied flat grain store

There were two (first December 8–11, 2001; second December 4–12, 2002) fumigations (Delicia Gastoxin; Delicia Freyberg GmbH, Delitzsch, Germany – a.i. phosphine 3 g/t) and one preventive structural residual spray (Reldan; Dow AgroSciences, Indianapolis, USA – a.i chlorpyrifos) treatments during the observed period (Figure 1). The efficacies of both

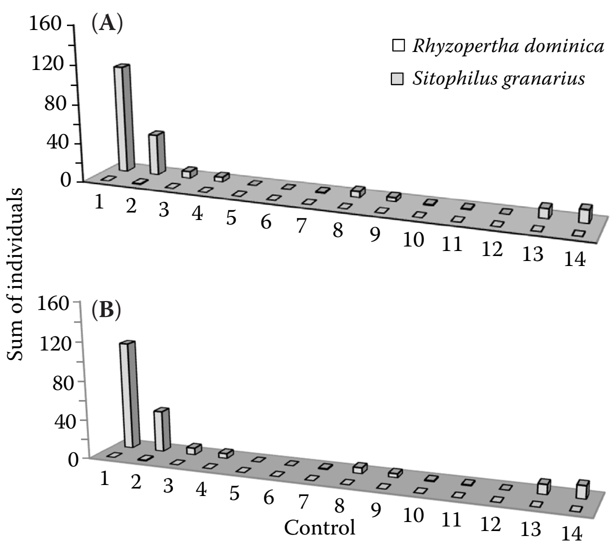

Figure 4. Captures of the ecological Group I pests in two types of (**A**) PC trap and (**B**) WB Probe II Trap in a flat grain store (capture events 1–14 were from October 2001 to December 2003 – capture events 1–3 were in 2001, 4–12 in 2002, and 13–14 in 2003)

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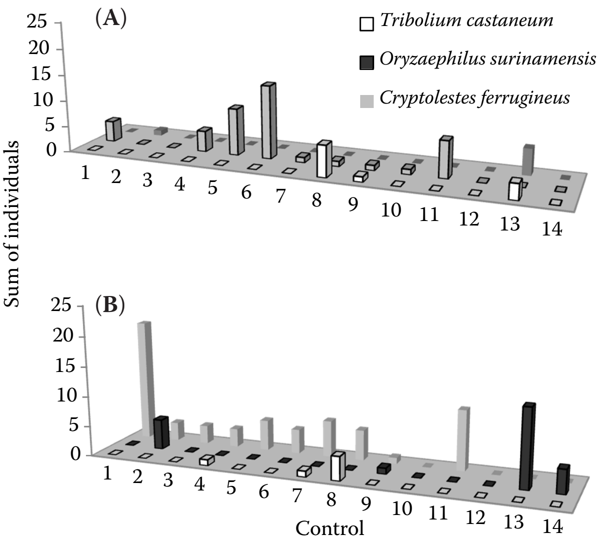

Figure 5. Captures of the ecological Group II pests in two types of (**A**) PC trap and (**B**) WB Probe II Trap in a flat grain store (capture events 1–14 were from October 2001 to December 2003 – capture events 1–3 were in 2001, 4–12 in 2002, and 13–14 in 2003)

fumigations were separately evaluated (as captures before and after treatment) by both traps. The comparisons showed differences in the sensitivity of both traps: a statistical comparison (a non-parametric test Wilcoxon rank test) showed significant differences in the captures before and after the fumigation of *S. granarius* in WB traps (Z = 2.023; P = 0.043) but with non-significant differences in PC traps (Z = 1.677; P = 0.093).

A comparison of both types of traps according to the three ecological groups of pests in particular capture events is shown in Figures 4–6. Average and median trapping efficacy of both types of traps according to the three ecological groups of pests (Figures 7–8) was compared using the Wilcoxon rank test, which showed insignificant differences in the capture efficacy of PC and WB Probe II traps for internal feeding primary (Group I) pests (Z = 0.392; P = 0.695) as well as for

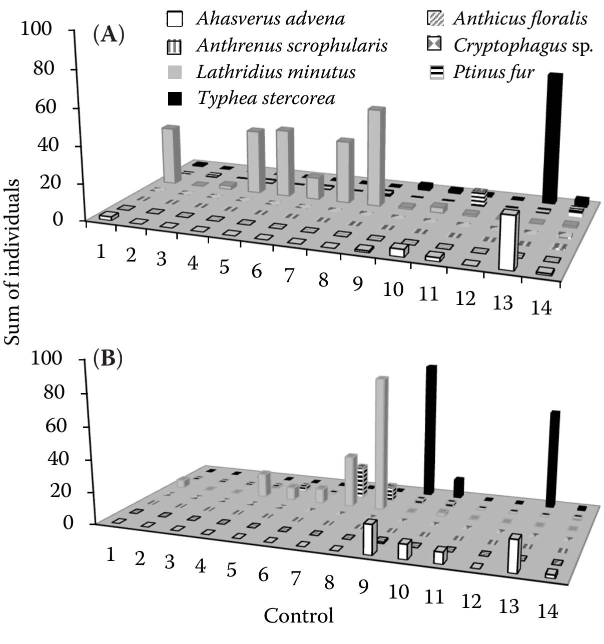

Figure 6. Captures of the ecological Group III pests in two types of (**A**) PC trap and (**B**) WB Probe II Trap in a flat grain store (capture events 1–14 were from October 2001 to December 2003 – capture events 1–3 were in 2001, 4–12 in 2002, and 13–14 in 2003))

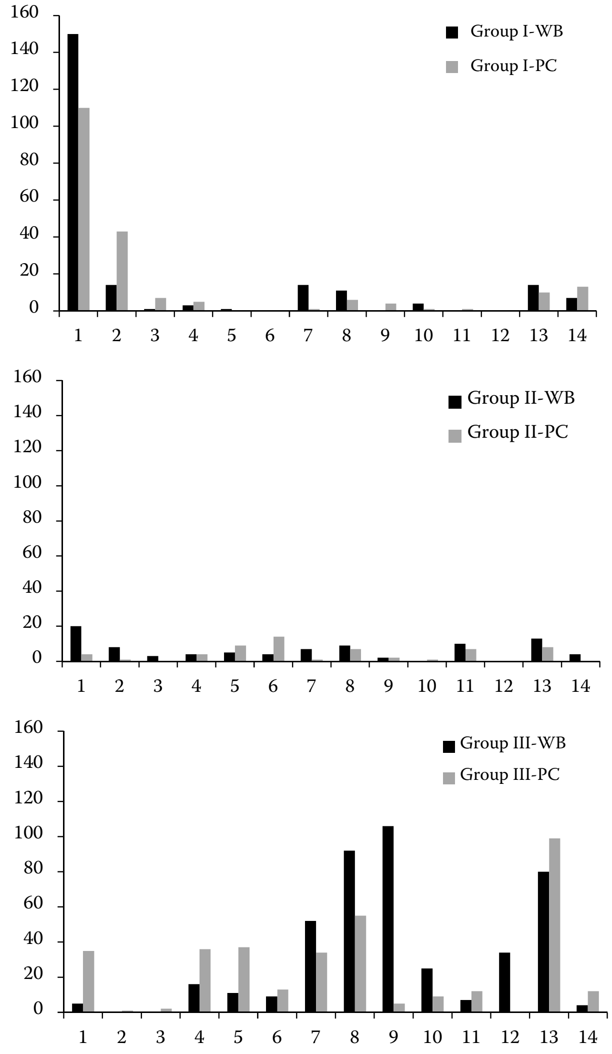

Figure 7. Captures of the ecological Group I, II, and III pests in two types of traps (PC and WB Probe II) in a flat grain store (capture events 1–14 were from October 2001 to December 2003 – capture events 1–3 were in 2001, 4–12 in 2002, and 13–14 in 2003)

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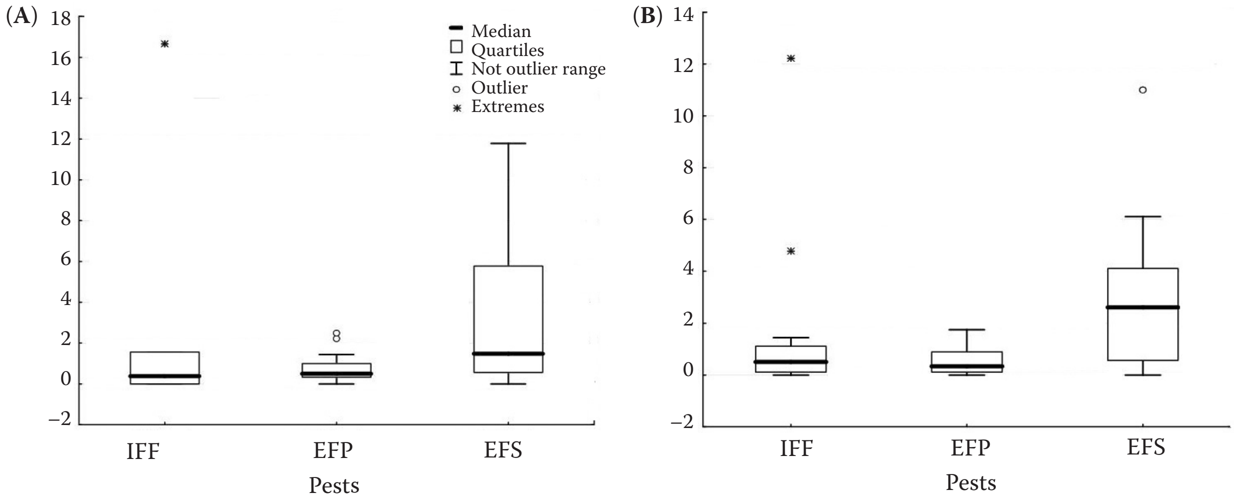

Figure 8. Median pooled catch in three groups of pests (IFP – Group I, primary internal feeding pests; EFP – Group II, primary external feeding pests; and EFS – Group III, secondary external feeding pests) during storage for a two-year period in (**A**) WB Probe II Trap and (**B**) PC trap

external feeding primary (Group II) pests (Z = 1.600; P = 0.11) and external feeding secondary (Group III) pests (Z = 0.534; P = 0.597). Figure 4 clearly presents the correlated captures of primary internal feeding pests (*S. granarius* and *R. dominica)* in both types of traps. It should be stressed that the conclusion for *R. dominica* is very weak because only two specimens were captured. For primary external feeding pests and secondary external feeding pests, the correlation between traps is less pronounced.

DISCUSSION

According to Trematerra and Throne (2012), the most common internal grain feeders are *Sitophilus granarius*, *S. oryzae* (L.), *S. zeamais* Motschulsky, and *R. dominica*. For the external grain-feeding insects, the most frequently encountered species are *Tribolium castaneum*, *T. confusum* J. du Val, *O. surinamensis*, *Cryptolestes ferrugineus* (Stephens), *Trogoderma granarium* Everts, *Plodia interpunctella* Hübner, and mites. Some insects, such as *Alphitobius diaperinus* (Panzer), *Ptinus fur* L., and *T. stercorea*, also feed on mould mycelia and dust and therefore they are indicators of mouldy and dusty conditions. In the present study, only three of the above-mentioned species were found to be the most frequent (*S. granarius*, *O. surinamensis,* and *T. stercorea*), supplemented by the other two (*L. minutus*, and *Ptinus fur* L.) (Table 2 and Figure 3). The succession of insects in stored products is a very complex phenomenon (Coombs & Woodroffe 1963, 1968, 1973; Nansen *et al.* 2004; Jian & Jayas 2012; Athanassiou *et al.* 2014) that needs additional attention. The major biotic factors influencing insect abundance and occurrence in traps in cereals are the presence of internal grain feeders, the presence of fungi, and the biochemical state of the grain. External feeders are rare in cereals that are undamaged by grain-handling equipment but increase markedly with prior infestation by primary pests. The damage caused by internal feeders to whole kernels may facilitate colonisation by secondary pests that continue to damage the cereals (Trematerra & Throne 2012). Each species that plays a role in this infestation chain is affected by and, to some extent, utilises any semiochemicals that are derived by the previous species in the same chain (Trematerra *et al.* 2015). The simultaneous presence of two species in the same area is expected to cause an alteration in their response. Similarly, a given commodity that is previously "contaminated" by a given species may affect the behaviour of another species that visits this commodity rather than a non-contaminated commodity. Trematerra *et al.* (2000) noted that kernels that were damaged by primary pests, especially by *S. oryzae*, were generally preferred by the externally feeding pests *O. surinamensis*, *T. castaneum*, and *T. confusum* over artificially damaged or whole kernels. Additionally, Athanassiou *et al.* (2006) found that seeds that were damaged by *S. oryzae* increased the response of other *S. oryzae* individuals.

Although pitfall traps of stored grain pests are cheap and very sensitive to discover the infectation, even

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at a low population pest density, their acceptance by farmers is suspiciously low (Adama *et al.* 2010). One of the reasons for this low acceptance is the complex information that has been presented on using the trap and interpreting the trap catch. Practitioners are overloaded by the scientific documentation that the stored-product beetle trapping pitfall traps efficiency is differentially influenced by the complex interplay of many factors, such as the type of trap (Cuperus *et al.* 1990), pest species (Athanassiou *et al.* 2001), physical condition, trap duration, type of food, etc. (Cogan & Wakefield 1994; Stejskal 1995; Trematerra 1998). Carvalho *et al.* (2004) found significant difference between pitfall and probe traps for monitoring in stored rice. On the contrary, Epenhuijsen *et al.* (2003) found pitfall cone trap to be more efficient than the probe trap or sampling spear to monitor *S. oryzae* in stored rice. In our experiments, we also found higher pooled catch in grain probes than in pitfall traps; but the difference was not as profound as the one reported by Carvalho *et al.* (2004) or Epenhuijsen *et al.* (2003). These differences might indicate that the trapping results are affected by the local conditions that may vary from year to year. In fact, even the short-term experiments comparing the efficacy of PC and WB Probe II traps on particular species showed that the results were, in some cases, significantly affected by a specific set of environmental conditions (Weston & Barney 1998; Wakefield & Cogan 2007). Small and middle-sized farmers do not require species-specific detailed information because their decision making-process is frequently irrespective of species but of ecological pest-group. In addition, these farmers tend to collect the data on grain quality for the whole long storage periods. Therefore, we tried to conduct and evaluate a trapping experiment from the perspective of small farmers.

Our experiments clearly show that the evaluation of whole ecological Groups I–III (Group I – internal feeding primary pests; Group II – external feeding primary pests; Group III – external feeding secondary pests) makes the species-specific efficacy differences between traps insignificant in long-term monitoring. However, significant differences between traps were found upon short-term evaluation. In the latter cases, the use of both traps is recommended because of the higher sensitivity and more precise evaluation of efficacy of the control treatment effects. This use agrees with the general methodical work on pitfall insect trapping by Schirmel *et al.* (2010), who found that capture efficiency of pitfall traps is highly affected by the sampling period and sampling intensity. These authors found that shorter sampling intervals are generally preferred because of the initial catch of large numbers of arthropods. Both long- and short-term trapping may be affected by changing temperatures if corrections are not performed (Saska *et al.* 2013). Schirmel *et al.* (2010) claimed that short sampling intervals are labour intensive and are therefore often very costly and could also affect the sampling sites because pitfall catches may be affected by a mechanical disruption "digging-in" (i.e., trap insertion into the material) and other disturbance effects, such as the 'trampling effect' (walking in then sampled area), as documented by Grandchamp *et al.* (2002). Schirmel *et al.* (2010) warned that the digging-in effect may result in sample bias because the catch is artificially increased in some places or layers of the sampled substrate. Consequently, this effect may lead to an overestimation of the local population density. In stored grain, the disruption issue is probably more important for mechanical sampling (using sampling spears, cups, and sieves) than for trap insertion. But even the insertion of traps requires disruptive movement of a human applicator on the sampled grain surface. There are several studies on stored-product insects. However, few studies have been performed as long-term studies lasting for more than one year (e.g. Epenhuijsen *et al.* 2003; Carvalho *et al.* 2004) that can prove or reject disturbing effects of sampling intensity.

CONCLUSION AND PRACTICAL RECOMMENDATIONS

This study has a practical message for the small or middle-sized farmers who require simple rules for their pest control decision making. When scientists provide farmers with a complex monitoring system, it is common for practitioners not to accept such a complex system because it is prohibitively time consuming and difficult to interpret. Epenhuijsen *et al.* (2003) found "the numbers caught in individual traps at similar population levels varied, which indicates that several traps should be set in each grain lot to give satisfactory estimations of weevil populations". Our study indicates that there was no need for the simultaneous use of both traps for long-term trapping, but for short-term trapping, especially when used for the effect of fumigants, the concurrent use

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of both traps is advised. It is also necessary to stress that it is desirable to extend the study to different types of storage and climatic conditions. Trapping efficacy of surface and subsurface traps may differ (e.g. Carvalho *et al*. 2004) because the distribution of insects is also different during storage time and period of the year (Atthanassiou *et al*. 2001).

References

Adama B.D., Siaplay M., Flinn P.W., Brorsen B.W., Phillips T.W. (2010): Factors influencing economic profitability of sampling-based integrated pest management of wheat in country elevators. Journal of Stored Products Research, 46: 186–196.

Armitage D. (1994): Some effects of grain cleaning on mites, insects and fungi. In: Proceedings 6th International Working Conference on Stored-product Protection, Canberra, Australia, April 17–23, 1994. Wallingford, CAB International: 896–901.

Arthur F.H., Campbell J.F., Toews M.D. (2014): Distribution, abundance, and seasonal patterns of stored product beetles in a commercial food storage facility. Journal of Stored Products Research, 56: 21–32.

Athanassiou C.G., Palyvos N.E., Eliopoulos P.A., Papadoulis G.T. (2001): Distribution and migration of insects and mites in flat storage containing wheat. Phytoparasitica, 29: 379–392.

Athanassiou C.G., Kavallieratos N.G., Trematerra P. (2006): Responses of *Sitophilus oryzae* (L.) and *Tribolium confusum* J. du Val to traps under pheromone and food volatiles. European Journal of Entomology, 103: 371–378.

Athanassiou C.G., Kavallieratos N.G., Throne J.E., Nakas C.T. (2014): Competition among species of stored-product psocids (Psocoptera) in stored grain. PLoS ONE, 9(8): e102867.

Buchelos C., Athanassiou C.G. (1999): Unbaited probe traps and grain trier: a comparison of the two methods for sampling Coleoptera on stored barley. Journal of Stored Products Research, 35: 397–404.

Carvalho M.O., Barbosa A.F., Magro A., Timlick B., Adler C., Marques P., Teixeira A., Jesus O., Mexia A. (2004): Insects of stored rice in Portugal: fungus-feeders, commodity-feeders and beneficials. In: Proceedings 5th Meeting Cost Action 842, WG4 "Biocontrol of Arthropod Pests in Stored Products". Barcelona, Spain, Oct 28–29, 2004: 11–15.

Cogan P.M., Wakefield M.E. (1994): The use of a managed bulk of grain for the evaluation of PC, pitfall beaker, insect probe and WBII Probe traps for trapping *Sitophilus granarius*, *Oryzaephilus surinamensis* and *Cryptolestes ferrugineus*. In: Proceedings 6th International Working Conference on Stored-product Protection, Canberra, Australia. April 17–23, 1994. Wallingford, CAB International: 390–396.

Coombs C.W., Woodroffe G.E. (1963): An experimental demonstration of ecological succession in an insect population breeding in stored wheat. Journal of Animal Ecology, 32: 271–279.

Coombs C.W., Woodroffe G.E. (1968): Changes in the arthropod fauna of an experimental bulk of stored wheat. Journal of Applied Ecology, 5: 563–574.

Coombs C.W., Woodroffe G.E. (1973): Evaluation of some of the factors involved in ecological succession in an insect population breeding in stored wheat. Journal of Animal Ecology, 42: 305–322.

Cuperus G.W., Fargo G.W., Flinn P.W., Hagstrum D.W. (1990): Variables affecting capture of stored-grain insects in probe traps. Journal of the Kansas Entomological Society, 63: 486–489.

Epenhuijsen van C.W., Bendall M.J., Sartie A. (2003): A comparison of methods for trapping riceweevils in stored wheat. New Zealand Plant Protection, 56: 233–238.

Grandchamp A.C., Niemela J.K., Kotze J. (2002): The effects of trampling on assemblages of ground beetles (Coleoptera, Carabidae) in urban forests in Helsinki, Finland. Urban Ecosystems, 4: 321–332.

Hagstrum D.W. (2000): Using five sampling methods to measure insect distribution and abundance in bins storing wheat. Journal of Stored Products Research, 36: 253–262.

Hagstrum D.W., Flinn P.W., Subramanyam Bh. (1998): Predicting insect density from probe trap catch in farm-stored wheat. Journal of Stored Products Research, 34: 251–262.

Hubert J., Kucerova Z., Aulicky R., Nesvorna M., Stejskal V. (2009): Differential vulnerability of stored wheat and barley to mite infestation in Czech grain stores. Insect Science, 16: 255–262.

Jian F., Jayas D.S. (2012): The ecosystem approach to grain storage. Agricultural Research, 1: 148–156.

Nansen C., Phillips T.W., Palmer M.W. (2004): Community analysis of insects in a stored-maize ecosystem. Ecological Research, 19: 197–207.

Saska P., Van der Werf W., Hemerik L., Luff M.L., Hatten T.D., Honek A. (2013): Temperature effects on pitfall catches of epigeal arthropods: a model and method for bias correction. Journal of Applied Ecology, 50: 181–189.

Schirmel J., Lenze S., Katzmann D., Buchholz S. (2010): Capture efficiency of pitfall traps is highly affected by sampling interval. Entomologia Experimentalis et Applicata, 136: 206–2010.

Stejskal V. (1995): The influence of food and shelter on the efficacy of a commercial sticky trap in *Tribolium cas-*

doi: 10.17221/30/2015-PPS

taneum (Coleoptera, Tenebrionidae). Journal of Stored Products Research, 31: 229–233.

Stejskal V., Hubert J. (2008): Risk of occupational allergy to stored grain arthropods and false pest-risk perception in the Czech grain stores. Annals of Agricultural and Environmental Medicine, 15: 115–167.

Stejskal V., Kucerova Z., Aulicky R., Lukas J. (2008): Method of sampling and laboratory extraction affects interpretation of grain infestation by storage pests. Journal of Plant Diseases and Protection, 115: 129–133.

Stejskal V., Aulicky R., Kucerova Z. (2014): Pest control strategies and damage potential of seed-infesting pests in the Czech stores – a review. Plant Protection Science, 50: 165–173.

Stejskal V., Hubert J., Aulicky R., Kucerova Z. (2015): Overview of present and past and pest-associated risks in stored food and feed products: European perspective. Journal of Stored Products Research, 64: 122–132.

Toews M.D., Phillips T.W., Payton M.E. (2005): Estimating populations of grain beetles using probe traps in wheat-filled concrete silos. Environmental Entomology, 34: 712–718.

Trematerra P. (1998): Capture of stored-grain coleoptera with WB Probe II Trap: Influence of grain type. Anzeiger für Schadlingskunde, Pflanzenschutz, Umweltschutz. 71: 135–137.

Trematerra P. (2013): Aspects related to decision support tools and Integrated Pest Management in food chains. Food Control, 34: 733–742.

Trematerra P., Throne J. (2012): Insect and mite pests of durum wheat. In: Sissons M., Abecassis J., Marchylo B., Carcea M. (eds): Durum Wheat, Chemistry and Technology. 2nd Ed. St. Paul, AACC International Inc.: 73–83.

Trematerra P., Sciarretta A., Tamasi E. (2000): Behavioural responses to volatiles from durum wheat kernels and host selection in *Oryzaephilus surinamensis* (Linnaeus), *Tribolium castaneum* (Herbst) and *Tribolium confusum* J. du Val. Entomologia Experimentalis et Applicata, 94: 195–200.

Trematerra P., Stejskal V., Hubert J. (2011): The monitoring of semolina contamination by insect fragments using the light filth method in an Italian mill. Food Control, 22: 1021–1026.

Trematerra P., Ianiro R., Athanassiou C.G., Kavallieratos N.G. (2015): Behavioral interactions between *Sitophilus zeamais* and *Tribolium castaneum*: the first colonizer matters. Journal of Pest Science, 88: 573–581.

Wakefield M.E., Cogan P.M. (2007): Laboratory evaluation of traps for the detection of beetle pests in bulk grain. Journal of Stored Products Research, 43: 546–549.

Weston P.A., Barney R.J. (1998): Comparison of three trap types for monitoring insect populations in stored grain. Journal of Economic Entomology, 91: 1449–1457.

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Corresponding author:

Ing. Radek Aulický, Ph.D., Výzkumný ústav rostlinné výroby, v.v.i., Odbor ochrany plodin a zdraví rostlin, Oddělení ochrany zásob a bezpečnosti potravin, Drnovská 507, 161 06 Praha 6-Ruzyně, Česká republika;
E-mail: aulicky@vurv.cz