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Journal of Stored Products Research 43 (2007) 97–102

Journal of STORED PRODUCTS RESEARCH

www.elsevier.com/locate/jspr

Differential natural performance of four *Cheyletus* predatory mite species in Czech grain stores

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Accepted 16 January 2006

Abstract

Out of four *Cheyletus* species occurring in grain stores in Central Europe, only *C. eruditus* is employed for the biocontrol of stored-pest arthropods. Unlike laboratory test data, field data on the differential natural performance (measured as frequency, abundance and predator-to-prey density dependence) of various species of *Cheyletus* spp. are not available. Therefore we investigated the relations between population densities of pest mites (Acari: Acaridida) and *Cheyletus* spp. predatory mites (Acari: Cheyletidae) in 147 grain stores in the Czech Republic. More than 1,000,000 individual pest mites and 40,000 individual predatory mites were extracted. We found that 29% of samples did not contain mites, 41% contained only pest mites, 4% only predatory mites, and in 26% both groups occurred simultaneously. Most abundant of the predatory mites were *C. eruditus* (79%) followed by "minor" species; *C. aversor* (10%), *C. trouessarti* (9%) and *C. malaccensis* (2%). There was a significant positive correlation between the occurrence and population density of the predatory and pest mites, except for *C. malaccensis.* Our results revealed *C. eruditus* as the mite predator with the highest natural performance in the field, indicating that it was the most pre-adapted species for biocontrol in central European grain stores.

Keywords: Storage; Grain; Infestation; Predatory mites; *Cheyletus*; *Acari*; Predator–prey interactions

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1. Introduction

The infestation of stored food products by mites and other arthropods is usually associated with three types of damage (Stejskal, 2001). Firstly, storage mites directly endanger human health due to allergenic contamination of food (Olsson and Hage-Hamsten, 2000; Arlian, 2002; Spiegel et al., 1995; Castillo et al., 1995; Scala, 1995; Matsumoto et al., 1996). Secondly, mites are vectors of toxicogenic fungi (Hubert et al., 2003) and thus indirectly contribute to contamination of food and feed with mycotoxins (Griffiths et al., 1959; Aucamp, 1969; Armitage and George, 1986; Franzolin et al., 1999; Hubert et al., 2004). Thirdly, mites cause significant grain weight losses and decrease of germinability (Rodionov, 1940; Solomon, 1946; Žd'árková and Reška, 1976).

Traditionally, the management of storage pest mites relies on chemical and physical measures (Norris, 1958; Thind and Dunn, 2002). While physical control remains a safe and efficient strategy, the use of acaricides causes problems because of toxic residues in food and rapidly increasing resistance (Szlendak et al., 2000). In addition, the USA and EU hygiene policies have been increasingly restricting the use of organophosphates, leaving the food industry without the only efficient class of registered acaricides, since most pyrethroids do not control mites satisfactorily (Wilkin and Hope, 1973). Biological control provides a feasible alternative or complement to pesticides in the food industry and stored grain IPM (Schöller and Flinn, 2000; Flinn and Hagstrum, 1996). Unfortunately, currently, biocontrol is almost absent in storage, in contrast to glasshouse, orchard or field environments. The literature review by Haines (1998), covering the past 30 years of stored-product pest control research, revealed that arthropod natural enemies in stored products are overlooked and underexploited. Collier and Steenwyk (2004) provide a critical review of prospects

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doi:10.1016/j.jspr.2005.12.002

for the use of augmentative biological control. The literature reports only one commercially sold bioagent for grain stores, Cheyletin$^{\text{TM}}$, based on the predatory parthenogenetic mite *Cheyletus eruditus* (Schrank) (Acari: Cheyletidae) (Pulpán and Verner, 1965; Žd'árková, 1986, 1998; Žd'árková and Horák, 1990). In Europe, pests of stored grain are documented to be predated not only by *C. eruditus* but several other species from the same genus (Žd'árková, 1979). However, no study documenting the differential field potential of *C. eruditus* and other *Cheyletus* species in stores under non-manipulated conditions is currently available.

Therefore, in this work we investigated differential natural performance (measured as frequency, abundance and predator-to-prey density dependence) of various *Cheyletus* spp. in Czech grain stores.

2. Methods

2.1. Sampled sites

The grain samples were obtained from 147 geographically isolated grain stores in the Czech Republic (Central Europe) during the years 1996–98 (Table 1). The samples

Table 1
Abundances and frequencies of pest and predatory mites in grain samples (recalculated to 1 kg of the grain) in the Czech Republic, sampled from 1996 to 1998

Year	1996				1997				1998			
Species	A			F	A			F	A			F
	Mean	Total	Max	(%)	Mean	Total	Max	(%)	Mean	Total	Max	(%)
Cheyletus aversor Rudendorf	1	250	250	0.4	8	1681	1125	10.0	30	1953	1818	4.5
Cheyletus eruditus (Schrank)	81	20,155	2567	22.3	27	5368	900	24.0	86	5687	1333	33.3
Cheyletus malaccensis Oudemans	2	450	440	1.2	0	35	35	0.5	3	205	200	3.0
Cheyletus trouessarti Oudemans	13	3296	1500	3.2	0	99	56	1.5	0	0	0	0.0
Acaropsellina docta (Berlese)	1	190	50	4.9	0	60	50	1.5	1	35	35	1.5
Acarus immobilis Griffiths	0	20	20	0.4	0	0	0	0.0	0	0	0	0.0
Acarus farris (Oudemans)	447	110,782	83,333	6.9	42	8454	6000	6.5	8	505	500	3.0
Acarus siro (Linnaeus)	1154	286,083	87,500	21.1	230	46,061	25,000	37.5	12	787	475	15.2
Aleuroglyphus ovatus (Troupeau)	0	0	0	0.0	0	10	10	0.5	0	0	0	0.0
Alliphis siculus (Oudemans)	3	625	400	0.8	0	70	50	1.0	1	97	67	3.0
Androlaelaps casalis (Berlese)	1	145	80	2.0	3	573	467	3.0	3	229	174	6.1
Blattisocius tarsalis (Berlese)	2	440	440	0.4	0	48	48	0.5	0	0	0	0.0
Blattisocius keegani Fox	1	100	91	1.6	0	0	0	0.0	0	0	0	0.0
Caloglyphus berlesei Michael	0	0	0	0.0	0	0	0	0.0	182	12,000	12,000	1.5
Caloglyphus oudemansi Zakhvatkin	40	10,000	10,000	0.4	0	0	0	0.0	5	350	350	1.5
Ctenoglyphus plumiger (C.L. Koch)	0	50	50	0.4	0	0	0	0.0	0	0	0	0.0
Eulaelaps stabularis (C.L. Koch)	5	1132	500	1.6	0	7	7	0.5	0	0	0	0.0
Glycyphagus domesticus (De Geer)	0	0	0	0.0	0	0	0	0.0	0	10	10	1.5
Glycyphagus privatus Oudemans	1	325	325	0.4	0	0	0	0.0	0	0	0	0.0
Haemogamasus pontiger (Berlese)	3	795	500	4.0	11	2205	2125	2.5	6	390	350	6.1
Hypoaspis lubrica Voigts et Oudemans	0	20	20	0.4	0	10	5	1.0	0	0	0	0.0
Chortoglyphus arcuatus (Troupeau)	62	15,388	7000	2.8	16	3209	2800	2.0	0	0	0	0.0
Leiodinychus krameri (G. Canestrini & R. Canestrini)	1	298	278	0.8	0	0	0	0.0	0	0	0	0.0
Lepidoglyphus destructor (Schrank)	147	36,489	25,000	29.1	61	12,191	3750	37.5	31	2013	750	40.9
Lepidoglyphus michaeli Oudemans	1	220	220	0.4	0	0	0	0.0	0	0	0	0.0
Proctolaelaps pygmaeus (J. Müller)	0	45	30	1.2	1	120	120	0.5	0	10	10	1.5
Pyemotes herfsi (Oudemans)	0	10	10	0.4	0	0	0	0.0	0	0	0	0.0
Spinibdella lignicola (G. Canestrini)	0	70	60	0.8	0	98	80	1.5	0	0	0	0.0
Tarsonemus granarius Lindquist	210	51,751	27,500	8.5	106	21,161	12,500	13.5	317	20,926	8667	16.7
Tydeus interruptus Thor	76	17,581	3000	18.6	539	107,710	43,750	21.5	202	13,351	5800	22.7
Tyrophagus longior (Gervais)	252	62,462	38,600	4.0	61	12,150	6000	3.0	1	43	43	1.5
Tyrophagus miripes Lynch	17	4200	4000	0.8	0	0	0	0.0	0	0	0	0.0
Tyrophagus neiswanderi Johnson & Bruce	0	10	10	0.4	0	0	0	0.0	0	0	0	0.0
Tyrophagus perniciosus Zakhvatkin	5	1333	833	0.8	0	65	40	1.0	0	0	0	0.0
Tyrophagus putrescentiae (Schrank)	108	26,718	25,000	7.7	290	57,938	50,000	22.5	82	5412	4250	16.7
Tyrophagus tropicus Robertson	0	10	10	0.4	0	0	0	0.0	0	0	0	0.0
Number of samples				247				200				66

Means of abundance are calculated from 1 kg grain samples taken throughout a year.
Total abundance values are numbers of all mites sampled, frequencies are occurrence (%) of particular species in samples, maxima of abundance are maximal numbers of mites in 1 kg samples. All parameters were calculated per appropriate year.
A, abundance; F, frequency.

were collected from September (IX) to April (IV). In each store, four to five store units (one "store unit" = one bin or flat store chamber) were sampled. As a result, a total of 514 store units were inspected and 514 samples of grain (2.5 kg) were collected. The plan for taking the sample from each store unit followed the standard method for application of Cheyletin (Žd'árková, 1998): each sample (2.5 kg grain) consisted of five sub-samples (0.5 kg grain) taken from five sampling points per store unit. Typical ranges of temperature (t) and moisture content (m.c.) at 1 m grain depth in Czech grain stores are as follows: IX: $t = 17-19\,^{\circ}\mathrm{C}$, m.c. = 12.8–13.4; X: $t = 17-19\,^{\circ}\mathrm{C}$, m.c. = 12.3–13.2%; XI: $t = 9-17\,^{\circ}\mathrm{C}$, m.c. = 12.8–13.5%; XII: $t = 5-13\,^{\circ}\mathrm{C}$, m.c. = 12.4–13.5%; I: $t = 3-10\,^{\circ}\mathrm{C}$, m.c. = 12.2–13.5%; II: $t = 2-9\,^{\circ}\mathrm{C}$, m.c. = 12.2–13.7%; III: $t = 0-9\,^{\circ}\mathrm{C}$, m.c. = 12.0–13.7%; IV: $t = -1$ to $+7\,^{\circ}\mathrm{C}$, m.c. = 12.0–13.7. The variability in these physical parameters is much higher at the grain surface during the winter ($t = -5$ to $+12\,^{\circ}\mathrm{C}$ and m.c. = 11–16%).

2.2. *Treatment of samples and data*

Each sample (2.5 kg) was gently mixed, then a 200 g subsample was placed in the Berlese–Tullgren funnel (exposure 24 h, temperature 40 °C). Mites were sorted out, counted and preserved, and mounted on microscopic slides for species determination. The abundance of each species was calculated for 1 kg of sample. The reported critical values of "efficient predator-to-prey ratio" ranged from 1:1 to 1:100 (Rodionov and Furman, 1940; Pulpán and Verner, 1965; Žd'árková, 1998). In our work we explored the relationship between the above mentioned predator-to-prey ratios and pest population density.

2.3. *Statistical analysis*

The probability of occurrence of the predatory mites was evaluated using the presence or absence of the predator as the binary response variable (Cox and Snell, 1990; Crawley, 1993), and the square root of the abundance of the pest mites as a covariate. The relationships between the densities of the predatory mites and the prey were evaluated with ln(Np + 1) abundance (Np) of the predator as the response variable, and ln(Ns + 1) abundance (Ns) of the storage mites as covariate. The adequacy of the fitted models was checked by plotting standardized residuals against fitted values, and by the normal probability plots of the fitted values (Crawley, 1993). Calculations were undertaken using general linear modelling (McCullagh and Nelder, 1989) in the commercial statistical package GLIM® v. 4 (Francis et al., 1994).

3. Results

We isolated more than 1,000,000 individual mites from a total of 514 samples taken from 514 store unit chambers. The herbi- and fungivorous mites were the most abundant and frequent (67% of samples were infested by pest mites) with a mean abundance of 1861 and a maximum of nearly 90,000 individuals per 1 kg grain sample.

The occurrence of pest and predatory mites together was traced in 26% of samples, while 4% of samples were infested by predatory mites alone (Fig. 1). Among 40,000 isolated individual predatory mites, four species of *Cheyletus* spp., (*C. eruditus*, *C. aversor* Rudendorf, *C. trouessarti* Oudemans and *C. malaccensis* Oudemans) were determined (Table 1). *Cheyletus eruditus* was the dominant predatory species (79%). Predatory mites of the genus *Cheyletus* occurred in 31% of all samples. The mean abundance was 76 individuals, and the maximum abundance was 2567 individuals per 1 kg grain sample.

The probability of occurrence of the predatory mites was directly dependent on the pest mite density ($\chi^2 = 58.29$; d.f. = 1; $P \ll 0.001$; $R^2 = 0.10$). The logit probability was described, for square roots of pest abundances, by the linear function: predatory mites = $-1.30 + (0.024 \times$ pest mites) (Fig. 2A). Also, the population density of the predatory mites was directly dependent on prey densities ($F = 83.99$; d.f. = 1, 362; $P \ll 0.001$; $R^2 = 0.19$). This relationship was described by the power function: predatory mites = $0.902 \times (\text{pest mites})^{0.3949}$ (Fig. 2B). Looking at each predatory mite species separately, the population density of the least abundant species, *C. malaccensis*, was independent of prey density (regression slope $b \pm$ SE on log–log scale $b = -0.01 \pm 0.01$, NS). The density dependence in *C. aversor* and *C. trouessarti*, which were also rare, was significant but very weak ($b = 0.061 \pm 0.019$ and 0.053 ± 0.017 for *C. aversor* and *C. trouessarti*, respectively, $P < 0.05$). Using the log–log scale, the density dependence in the population of the dominant species, *C. eruditus*, was about seven times stronger than in *C. aversor* and *C. trouessarti*.

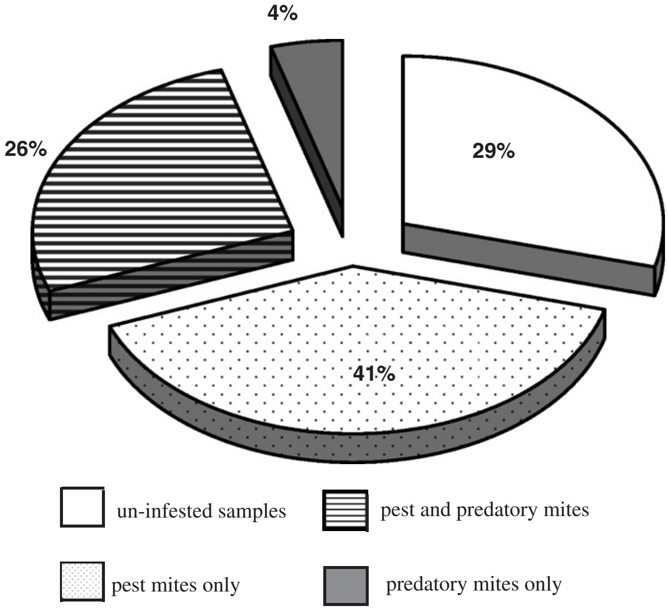

Fig. 1. Mite occurrence in 514 evaluated stored grain samples.

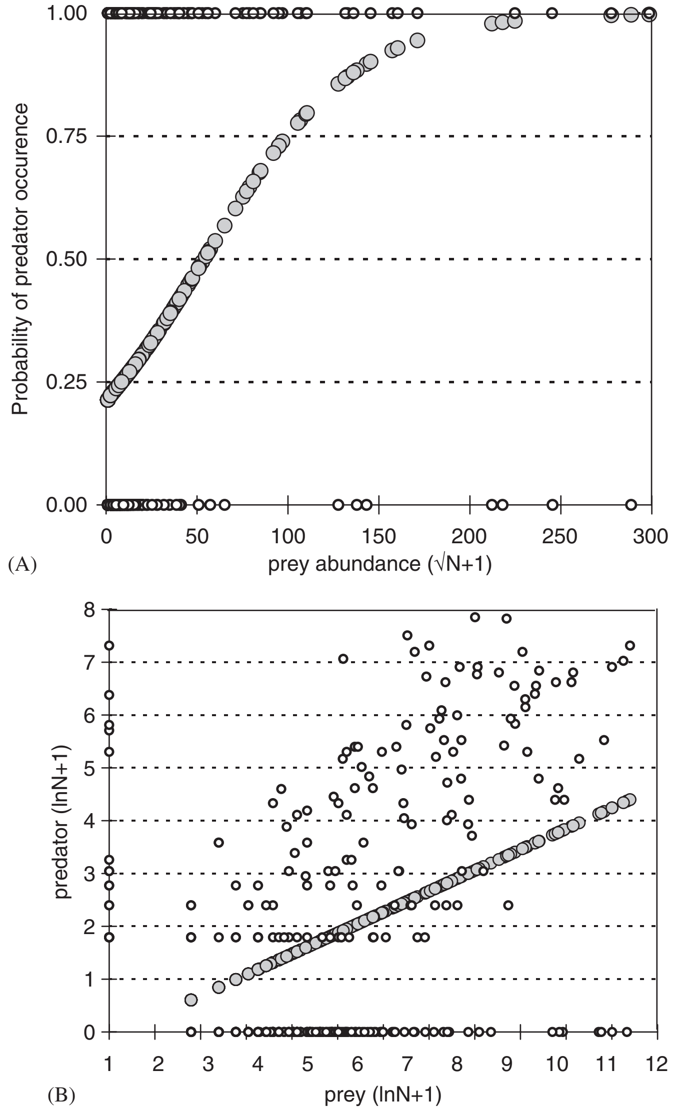

Fig. 2. The probability of predatory mites occurrence (A) and their density (B) related to prey density; (○) observed, (◉) fitted values. Abundance data were transformed using square-root transformation (A) and logarithmic transformation (B). Statistical significance and parameter estimates are in the text.

Table 2
Relationship among different predator–prey ratios and numbers of prey in the grain samples

Predator–prey ratio	Number of samples			
Prey abundance	Below 1000 individuals	More than 1000 individuals	Total	(%)
Without prey			23	4.47
7/1–1/1	19	1	20	3.89
1/1.1–1/40	56	34	90	17.51
1/40–1/100	6	6	12	2.33
1/100–1/620	2	12	14	2.72
Total	83	53	159	30.93

The relationship was estimated from the 159 grain samples in which predatory mites were present (Fig. 1).

Table 2 shows that the predator–prey ratio and pest population density are not randomly associated: *G*-test on contingency table (with the category 7/1–1/1 pooled with 1/1–1/40, and 1/100–1/620 with 1/40–1/100): $\chi^2 = 12.159$, d.f. = 1, $P < 0.0005$.

4. Discussion

It is known that various natural enemies frequently accompany pest mites occurring in grain stores. This work shows that in the Czech Republic, pest mites are associated with four species of predatory mites of the genus *Cheyletus* spp. (*C. eruditus*, *C. malaccensis, C. aversor* and *C. trouessarti*). A similar natural composition of predatory mite species is reported not only from various regions of Europe (Solomon, 1946; Armitage et al., 1994; Emmanouel et al., 1994; Iversen et al., 1990; Franz et al., 1997; Hage-Hamsten and Johansson, 1992, 1998; Harfast et al., 1996; Stejskal et al., 2003; Kučerová et al., 2003) but also from North America (Sinha and Wallace, 1973; Sinha and Kawamoto, 1990). In our study, the most abundant and frequent species was *C. eruditus* followed by three species *C. malaccensis, C. aversor* and *C. trouessarti* of "minor importance" in terms of their frequency and population density. There was a significant positive correlation between the occurrence and population density of the predatory and pest mites except for *C. malaccensis* (Fig. 2) indicating that the occurrence of *Cheyletus* predators (*C. eruditus*, *C. aversor* and *C. trouessarti)* and their prey are either density dependent or regulated by the same physical factors (e.g., temperature, humidity, cleaning). Provided that the density-dependent relationship was an effect of predatory activity, our data indicated a high predatory potential from the natural occurrence of *C. eruditus* in Czech grain stores. The presence of 4% of samples with predators alone could be explained as the result of eradication of prey by predatory mites. Here, it is interesting to note that after prey eradication, the *Cheyletus* population can be self-maintaining for some time via cannibalism (Solomon, 1969a, b; Žd'árková, 1998).

The data obtained led us to the conclusion that *C. eruditus* was the most pre-adapted species for Czech grain stores, while other *Cheyletus* species (*C. aversor, C. trouessarti* and *C. malaccensis)* had lower colonization potential in this environment. Of the three minor *Cheyletus* species, *C. malaccensis* showed the lowest potential for biocontrol because of its low frequency and insignificant density dependence on populations of pest mites. On the contrary, in Southern Europe (Athanassiou et al., 2002) and Asia (Putatunda, 2002), *C. malaccensis* was reported as a major predatory mite in grain storage systems. Putatunda (2002) even claimed that *C. malaccensis*, which was present in very high numbers in Indian stores, may have been keeping the mite pest population under control.

Besides physical critical conditions (see Solomon, 1969a), some authors claim that successful control of pest mites requires a certain critical range of *Cheyletus* predator-to-prey ratio; e.g. Rodionov and Furman (1940) reported this ratio as 1:40 for flour and Žd'árková (1998) reported 1:1–1:100 for stored grain. The importance of low predator-to-prey ratios was confirmed by our study: decreasing density of pest mites in samples was frequently associated with low predator-to-prey ratios (Table 2). However, we also found situations of high pest populations (i.e., ''unsuccessful control'') within the range of claimed predator–prey ratios of efficiency. This indicates that there are other critical conditions that determine the final outcome of the interaction between prey and predator, such as temperature, humidity and length of interaction time (Solomon, 1969a; Pekár and Žd'árková, 2004). It is known (Žd'árková and Horák, 1999) that decreasing temperatures decrease the development of *Cheyletus* spp. more rapidly than those of pest mites, in particular *Acarus siro* L. Under sub-optimal temperature conditions, predatory mites cannot reach the required level of pest control (Solomon, 1962, 1969b). Thus, in the case of quickly lowering autumn temperatures in grain stores, the reproductive rate of *Cheyletus* predators may not be sufficient for successful biological control. It remains open to what extent artificial increase in predator numbers can be helpful under such adverse conditions. Although the recommended range of critical predator-to-prey ratios leads to ''statistically'' better results (Table 2), it is not an adequate or safe decision-making tool for use by farmers in risk aversion. Thus, what is urgently needed for biocontrol of *Cheyletus* spp. is a predator–prey population model that includes not only critical ratios but also other key limiting parameters for this system, such as temperature, humidity and grain moisture content.

Acknowledgements

This work was supported by grants MZE-000-2700063.

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