The influence of the type of storage on pest infestation of stored grain in the Czech Republic

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ABSTRACT

Stored-product pests cause high economic losses by feeding on stored grain and endanger the public health by contamination of food by allergens. Therefore, the aim of this work was to explore whether the risk of infestation of stored grain by pests is different in various types of storage premises. We compared the level of infestation and the pest species composition in the two main types of grain stores in Central Europe that includes horizontal flat-stores (HFS) and vertical silo-stores (elevators) (VSS). A total of 147 grain stores located in Bohemia, Czech Republic was inspected. We found that both types of stores were infested with arthropods of three main taxonomic groups: mites (25 species, 120 000 individuals), psocids (8 species, 5 600 individuals) and beetles (23 species, 4 500 individuals). We found that VSS and HFS differ in species composition of mites, psocids and beetles. However, the primary grain pests (i.e. *Lepidoglyphus destructor*, *Acarus siro*, *Tyrophagus putrescentiae*, *Lachesilla pedicularia*, *Sitophilus oryzae*, *Rhyzopertha dominica*, *Oryzaephilus surinamensis* and *Cryptolestes ferrugineus*) occurred in both types of stores. The only exception was higher frequency and abundance of two serious beetle-pests (*Tribolium castaneum, Sitophilus granarius*) in HFS than in VSS. The total numbers of mite and beetle species infesting VSS and HFS was almost the same. There was higher psocid species diversity in VSS than in HFS. The difference between the total (i.e. level of pest infestation per kg of grain sample) numbers of mite and psocid individuals collected from VSS and HFS was not significant. However, the total numbers of beetle-pest individuals collected from HFS was twice the amount collected from VSS. We concluded that both types of stores are equally risky in terms of mite and psocid infestation. HFS is more risky for grain storage than VSS in terms of beetle infestations, although even the VSS structures cannot be in no way called pest-safe. The VSS and HFS microclimatic conditions (humidity, temperature) are discussed in relation to mite, psocid and beetle infestation.

Keywords: food; grain; storage; silo; bulk stores; pests; mites; psocids; beetles

Production of grain-crops at the farm level is a value-added agricultural process that includes both field planting and storage of grain. The economical outcome of this process is influenced by many biotic and abiotic factors and their mutual interactions. Infestation of grain by arthropods belongs among the most economically important biotic factors; since these pests cause enormous losses of stored products each season worldwide (Subramanyam and Hagstrum 1996). The type of storage technology is considered a serious abiotic factor influencing the stored-grain quality. Industrial buildings differ in their level of isolation to prevent colonisation by outdoor pests (Murphy and Todd 1993). For example, Mann et al. (1999) found that adults of *Cryptolestes ferrugineus* were unable to infest wheat grain stored in sealed metal bin-containers. It is also known that the grain stored in metal silo bins is less accessible to rodent infestation than the one stored in flat-hangar stores. In addition, various storage premises differ in their physical properties, storage microclimate, and its spatio-temporal dynamics within the storage season. The thorough understanding of how the storage condition influences various pests may enable the prediction of the risk of infestation of particular type of grain store. Until recently, the published studies have mostly analysed the separated effects of the abiotic factors on pest populations, i.e. climate (e.g. Zijun et al. 1999), humidity and temperature (Maier and Montross 1999). However, there are few studies (e.g. White et al. 1999) exploring the influence of the whole complex of abiotic factors on pests that are associated with a particular type of grain store.

Therefore the aim of the study was to explore whether there are some differences in the level of infestation and the pest species composition in the two main types of grain stores in the Central Europe that include (i) horizontal flat-stores (HFS) and (ii) vertical silo-stores – elevators (VSS). The study is a part of a long-term research program on fauna of the agricultural and food stores in Czech Republic (e.g. Stejskal and Kučerová 1996, Žďárková 1998b, Stejskal and Horák 1999, Stejskal et al. 1999, 2002, Hubert et al. 2002, Stejskal and Hubert 2002).

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MATERIAL AND METHODS

Sampled sites. The grain samples were collected from 147 geographically isolated grain stores in the Czech Republic during the years 1996–1998. We inspected (i) 80 horizontal flat-stores (bulks) (HFS) (53 one-storey and 27 multi-storey stores) and (ii) 67 vertical silo-stores (elevators) (VSS). A total of 379 grain samples (2.5 kg each) were collected. Each sample consisted of 5 sub-samples (0.5 kg) taken from 5 sampling points (Stejskal 2002) from one chamber of HFS or VSS. The type of grain was treated as a covariate in this part of study and includes wheat (60%) and barley (40%) grain samples.

Treatment of samples. Each sample was gently mixed, then a 200 g subsample was placed on the Berlese-Tullgren funnel (exposure 24 hrs, temperature 40°C). The biological material (Acarina, Psocoptera) was sorted out, preserved and finally mounted on microscopic slides for species determination. The rest of the sample was placed on the sieving machine with a mesh corresponding to the examined commodity. The macro-arthropods pests (i.e. Coleoptera, Lepidoptera, part of Psocoptera) were then picked up manually from both the oversize and undersize fractions and determined using stereomicroscope or microscope.

Statistical analysis. The abundance of particular species was recalculated to become comparable (e.g. related to 1 kg of commodity). In order to find a difference between HFS and VSS, we compared: (i) The proportion of infested/un-infested grain in both types of stores. The frequency of infested and un-infested samples were analysed using Contingency tables (Statistica software®) for each arthropod group separately. (ii) Numbers of species and individuals of arthropod pest groups using Kruskal-Wallis Anova median test (Statistica software®). The un-infested samples were excluded from the analysis. (iii) The pests composition and their abundances were compared using redundancy analysis – RDA (Sinha 1977, Jogman et al. 1987). The abundance values were analysed for each group of pest separately. Type of store (i.e. VSS and HFS) was used as an environmental variable and the kind of stored grain and season as covariates (Canoco software).

RESULTS

Samples from both VSS and HFS were infested with three major groups of storage arthropods, mites (25 species, 120 000 individuals), psocids (8 species, 5 600 individuals) and beetles (23 species in about 4 500 individuals). The moths were not observed. Mite infestation was found in more than 60% of the grain samples (Figure 1). Mites were the most abundant group of pests (Figure 2). Psocids and beetles infestation was lower (cca 20% of grain samples) as well as their abundance. The numbers of infested samples by mites and beetles were similar in VSS and HFS ($\chi^2_{(1.376)} = 3.61, p = 0.06$; $\chi^2_{(1.376)} = 0.30, p = 0.30$), while psocids infested higher proportion of samples from VSS ($\chi^2_{(1.376)} = 4.04, p = 0.04$).

The number of species and numbers of individuals per sample (Figure 2) were similar in VSS and HFS:
mites: $H_{(1.243)} = 0.91, p = 0.24$; $H_{(1.243)} = 0.10, p = 0.76$
psocids: $H_{(1.72)} = 0.01, p = 0.92$; $H_{(1.72)} = 0.01, p = 0.93$
beetles: $H_{(1.114)} = 0.12, p = 0.72$; $H_{(1.114)} = 1.06, p = 0.30$

Species composition of mite species groups significantly differed between VSS and HFS (test of significance of all canonical axes: F-ratio = 3.16, $p = 0.02$). Similar trends showed psocids and beetles species (F-ratio = 4.24, $p = 0.01$ and F-ratio = 2.89, $p = 0.02$).

Based on RDA we distinguished three groups of species: (i) VSS-associated species; (ii) HFS-associated species and (iii) species infesting both types of stores (i.e. VSS and HFS). The position of species on the first axis (Tables 1–3) was used as a criterion to define pest species affinity to occur more often in VSS or HFS. *Tarsonemus granarius* and *Tydeus interruptus* were the most specific pest-mite species infesting VSS (Table 1), whereas *Acarus farris* and *Cheyletus aversor* were the most specific HFS mite-pest species (Table 1). Importantly, the most economically important mite pests (i.e. *Lepidoglyphus destructor*, *Acarus siro*, *Tyrophagus*

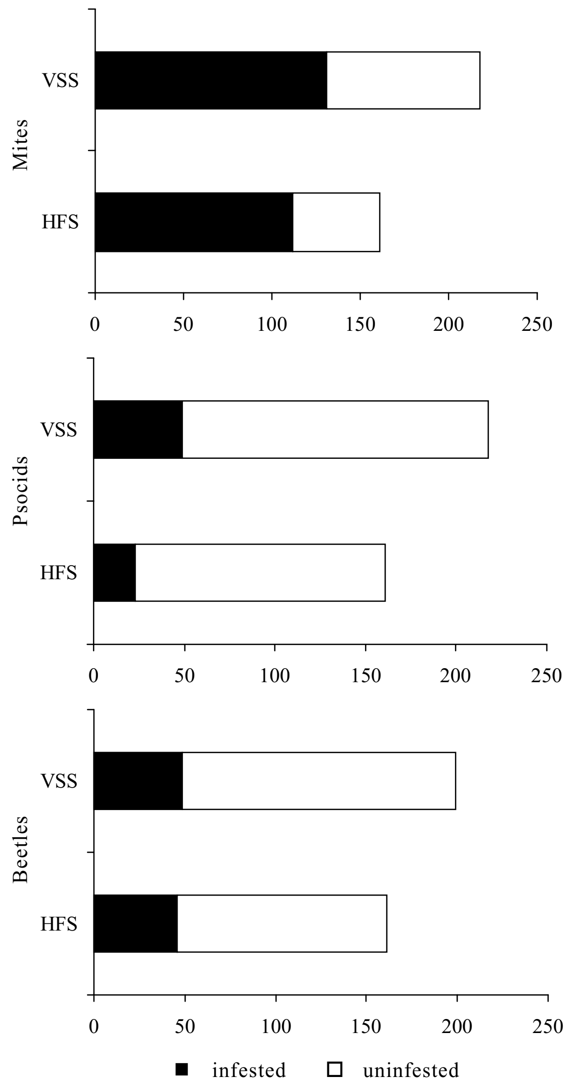

Figure 1. The comparison of proportion of infested grain samples in HFS and VSS

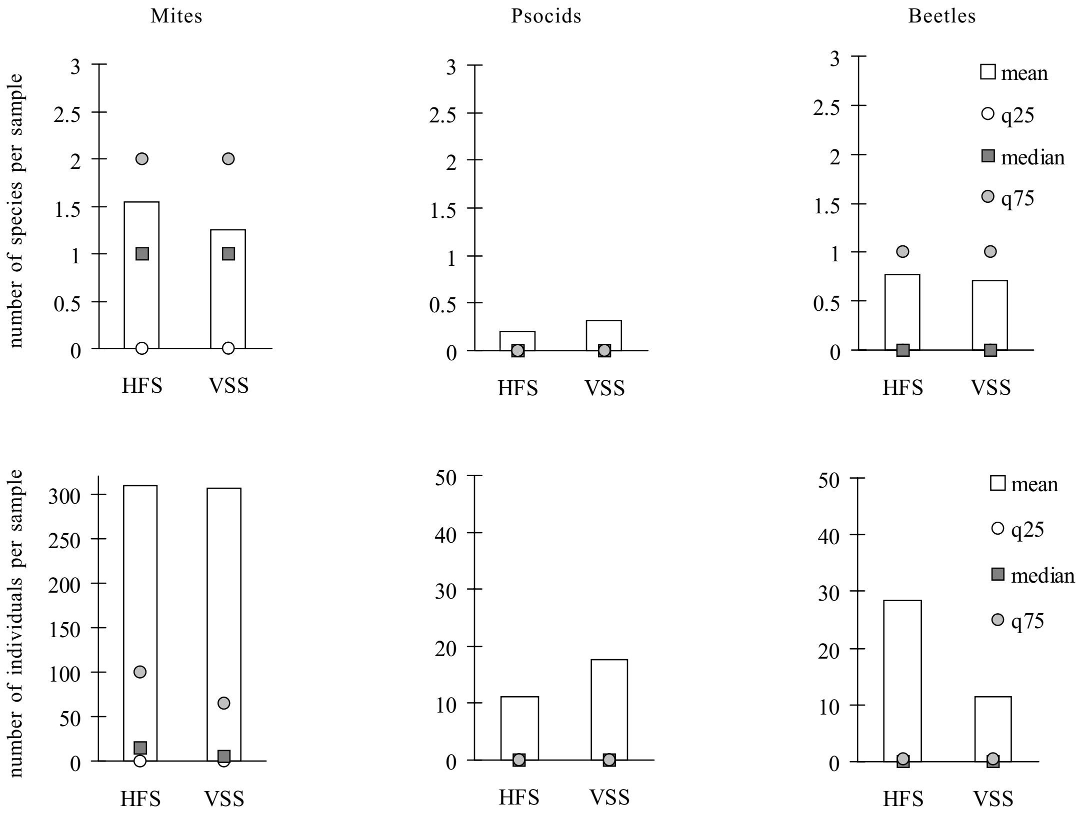

Figure 2. The comparison of numbers of species and abundance of arthropod groups in HFS and VSS (the un-infested samples were not included into analysis)

putrescentiae) and predatory mite *Cheyletus eruditus* occurred frequently and massively in both VSS and HFS (Table 1, Figure 3). The most typical pest psocids infesting VSS include *Liposcelis brunnea*, *L. entomophila*, *L. decolor* and *Lepinotus patruelis* (Table 2). Only one psocid species (*Liposcelis paeta*) was typically associated with HFS (Figure 3) and one psocid species (*Lachesilla pedicularia*) was associated with both types of stores. Beetles of minor economical importance were typical for VSS (Table 3). Serious feeding pests such as *Tribolium castaneum*, *Sitophilus granarius* together with serious contaminators (*Lathridius minutus*, *Typhea stercorea*) belonged to typical pest species infesting HFS (Figure 3). Nevertheless, similarly as in mites, the remainder of most serious grain infesting pests (*Sitophilus oryzae*, *Rhyzopertha dominica*, *Oryzaephilus surinamensis* and *Cryptolestes ferrugineus*) occur equally in both types of stores (Figure 3).

DISCUSSION

Overall arthropod infestation of the Czech grain stores

We found almost 130 000 pest arthropods in 379 samples taken from 147 Czech grain stores. This represents an average infestation of 343 arthropods per one sample of grain taken from any type of the Czech grain store. We can conclude that overall infestation of all types of Czech stores by stored product pests was quite high provided that there is a zero pest tolerance in grain in EU countries (Bode 1996). This may have not only economical but also public health implication for the Czech Republic since many stored product pests are known as allergenic (Olsson and Hage-Hamsten 2001, Arlian 2002, Hubert et al. 2002, Stejskal and Hubert 2002).

Species composition and numbers in both types of stores (i. E. VSS vs. HFS)

Although the RDA analysis of our data revealed that both type of stores differed in their typical pest species composition it should be noted that, in most cases, the most economically important species of mites and beetle grain pests occurs in both types of stores. The only exception was higher occurrence of damaging pests *Tribolium castaneum* and *Sitophilus granarius* in HFS. Both species prefer surface grain infestation (Subramanyam and Hagstrum 1996). Thus, we can speculate that HFS structure provides better conditions for this beetle species than VSS due to the higher surface to volume ratio of grain mass in flat stores than in silos. Based on our

Table 1. The list of mites and their occurrence in HFS and VSS; first canonical axis explained 1% of the total variation in the dataset

Species		Horizontal flat store			Vertical silo-store			Total
	ax1	N	D	F	N	D	F	N_T
Mites		49 730			66 925			116 655
VSS-associated species								
Cheyletus malaccensis	–1.63	–	–	–	250	0	2	250
Pyemotes herfsi	–1.40	–	–	–	10	0	0	10
Chortoglyphus arcuatus	–1.32	–	–	–	5	0	0	5
Cheyletus trouessarti	–0.80	–	–	–	25	0	1	25
Tarsonemus granarius	**–0.62**	15 575	31	3	**3 690**	**6**	**10**	19 265
Spinibdella lignicola	–0.46	–	–	–	5	0	0	5
Aleuroglyphus ovatus	–0.38	–	–	–	10	0	0	10
Acaropsellina docta	–0.32	100	0	4	115	0	3	215
Tydeus interruptus	**–0.31**	1 675	3	14	**38 790**	**58**	**12**	40 465
Androlaelaps casalis	–0.31	65	0	3	70	0	2	135
VSS- and HFS-associated species								
Lepidoglyphus destructor	**–0.23**	**3 050**	**6**	**42**	**8 835**	**13**	**33**	11 885
Cheyletus eruditus	**–0.19**	**1 325**	**3**	**14**	**1 900**	**3**	**18**	3 225
Acarus siro	**0.25**	**13 365**	**27**	**30**	**11 345**	**17**	**19**	24 710
Tyrophagus putrescentiae	**0.43**	**11 900**	**24**	**19**	**1 650**	**2**	**15**	13 550
HFS-associated species								
Haemogamasus pontiger	0.45	485	1	6	60	0	1	545
Hypoaspis lubrica	0.48	20	0	1	10	0	1	30
Caloglyphus oudemansi	0.50	350	1	1	–	–	–	350
Glycyphagus domesticus	0.50	10	0	1	–	–	–	10
Blattisocius keegani	0.90	95	0	1	5	0	0	100
Tyrophagus longior	0.92	45	0	1	10	0	0	55
Proctolaelaps pygmaeus	0.99	15	0	1	–	–	–	15
Tyrophagus neiswanderi	1.04	10	0	1	–	–	–	10
Tyrophagus tropicus	1.04	10	0	1	–	–	–	10
Acarus farris	**1.10**	**1 210**	**2**	**7**	60	0	2	1 270
Cheyletus aversor	**1.20**	**425**	**1**	**5**	80	0	4	505

ax1 – the species score on the first conical axis (RDA), D – dominance (%), F – frequency (%), N – total abundance

data VSS seems to be able to support more psocid species than HFS. Currently we have no explanation for this difference. It is also hard to compare overall species composition infesting HFS and VS in the Czech Republic and other European countries since no similar comparative study is currently available. In Canada, Sinha and Watters (1985) found that the composition of stored grain pest differed in elevators and mills. However, even in this study the information on flat-store fauna is missing. The pest species composition in Czech (Table 1) and Canadian elevators (i.e. VSS) was different. The following species are listed according decreasing frequency in samples from Canadian elevators (1969–1981): *Tenebrio molitor*, *Nemapogon granellus*, *Attagenus* spp., *Cryptolestes ferrugineus*, *Acari*, *Sitophilus granarius*, *Cryptolestes pusillus*, *Sitophilus oryzae*, *Pyralis farinalis*, *Tenebroides mauritanicus*. However, in Canadian farms, the principal granivores were *Cryptolestes ferrugineus* and *Tribolium castaneum* (Madrid et al. 1990).

Level of infestation and pest abundance in both types of stores (i.e. VSS vs. HFS)

In both types of stores, the most abundant and frequent were mites followed by psocids and beetles while no lepidopteran pest was found. Our results showed that the type of storage did not influence the overall abundance and proportion of infested grain samples of mite and psocid pests in both types of stores. However, different situation was found in beetles: there was almost double number of individuals collected from HFS (4 566 sampled beetles) than VSS (2 471 beetles) (Table 3). What is the explanation for this storage effect leading to increasing risk of infestation by mites but not by beetles in both types of stores? It is probably due to differences in subsurface and surface temperature and humidity conditions of flat and silo stores and different reaction of both pest groups to these conditions. It is documented that mite and beetles react differently to humidity and temperature:

Table 2. The list of psocids and their occurrence in HFS and VSS; first canonical axis explained 6% of the total variation in the dataset

Species	ax1	Horizontal flat store N	D	F	Vertical silo-store N	D	F	Total N_T
Psocids		1 806			3 825			5 631
VSS-associated species								
Liposcelis brunnea	**–3.1764**	–	–	–	**25**	**1**	**1**	25
Lepinotus patruelis	**–0.441**	1	0	1	**151**	**4**	**5**	151
Liposcelis entomophila	**–0.2674**	–	–	–	**1 496**	**39**	**3**	1 496
Liposcelis decolor	**–0.2524**	175	10	6	**1 568**	**41**	**13**	1 743
VSS- and HFS-associated species								
Lachesilla pedicularia	**0.3194**	**89**	**5**	**6**	**267**	**7**	**3**	355
HFS-associated species								
Liposcelis paeta	**0.4002**	**1 441**	**80**	**2**	36	1	1	1 477
Liposcelis corrodens	0.5535	8	0	2	265	7	5	273
Lepinotus reticulatus	**1.1779**	**93**	**5**	**2**	17	0	1	110

ax1 – the species score on the first conical axis (RDA), D – dominance (%), F – frequency (%), N – total abundance

Table 3. The list of beetles and their occurrence in HFS and VSS; first canonical axis explained 3% of the total variation in the dataset

Species	ax1	Horizontal flat store N	D	F	Vertical silo-store N	D	F	Total N_T
Beetles		4 566			2 471			7 037
VSS-associated species								
Lasioderma serricorne	–1.66	–	–	–	0	0	0	0
Attagenus unicolor	–1.66	–	–	–	1	0	1	1
Palorus ratzeburgi	–1.65	–	–	–	6	0	1	6
Cryptolestes turcicus	–1.65	–	–	–	3	0	0	3
Ptinus raptor	–1.59	–	–	–	2	0	1	2
Stegobium paniceum	–1.58	–	–	–	1	0	0	1
VSS- and HFS-associated species								
Sitophilus oryzae	**–0.64**	**264**	**6**	**4**	**569**	**23**	**15**	833
Rhyzopertha dominica	**–0.53**	**628**	**14**	**4**	**644**	**26**	**8**	1 272
Cryptolestes pusillus	–0.36	68	1	4	50	2	3	118
Oryzaephilus surinamensis	**–0.20**	**501**	**11**	**12**	**515**	**21**	**7**	1 016
Cryptolestes ferrugineus	**0.07**	**754**	**17**	**7**	**497**	**20**	**9**	1 251
HFS-associated species								
Anthicus floralis	1.49	2	0	1	–	–	–	2
Ptinus fur	1.29	25	1	1	2	0	2	27
Ahasverus advena	0.92	62	1	6	12	0	3	74
Niptus hololeucus	0.65	1	0	1	–	–	–	1
Tenebrio molitor	0.64	2	0	1	–	–	–	2
Tribolium castaneum	**0.61**	**1 337**	**29**	**10**	74	3	6	1 411
Ptinus latro	0.59	1	0	1	–	–	–	1
Lathridius minutus	**0.58**	**209**	**5**	**4**	1	0	1	210
Typhaea stercorea	**0.50**	**241**	**5**	**7**	20	1	1	260
Sitophilus granarius	**0.32**	**468**	**10**	**9**	75	3	11	543
Tribolium confusum	0.22	2	0	2	0	0	0	2
Ptinus tectus	0.17	2	0	1	0	0	0	2

ax1 – the species score on the first conical axis (RDA), D – dominance (%), F – frequency (%), N – total abundance

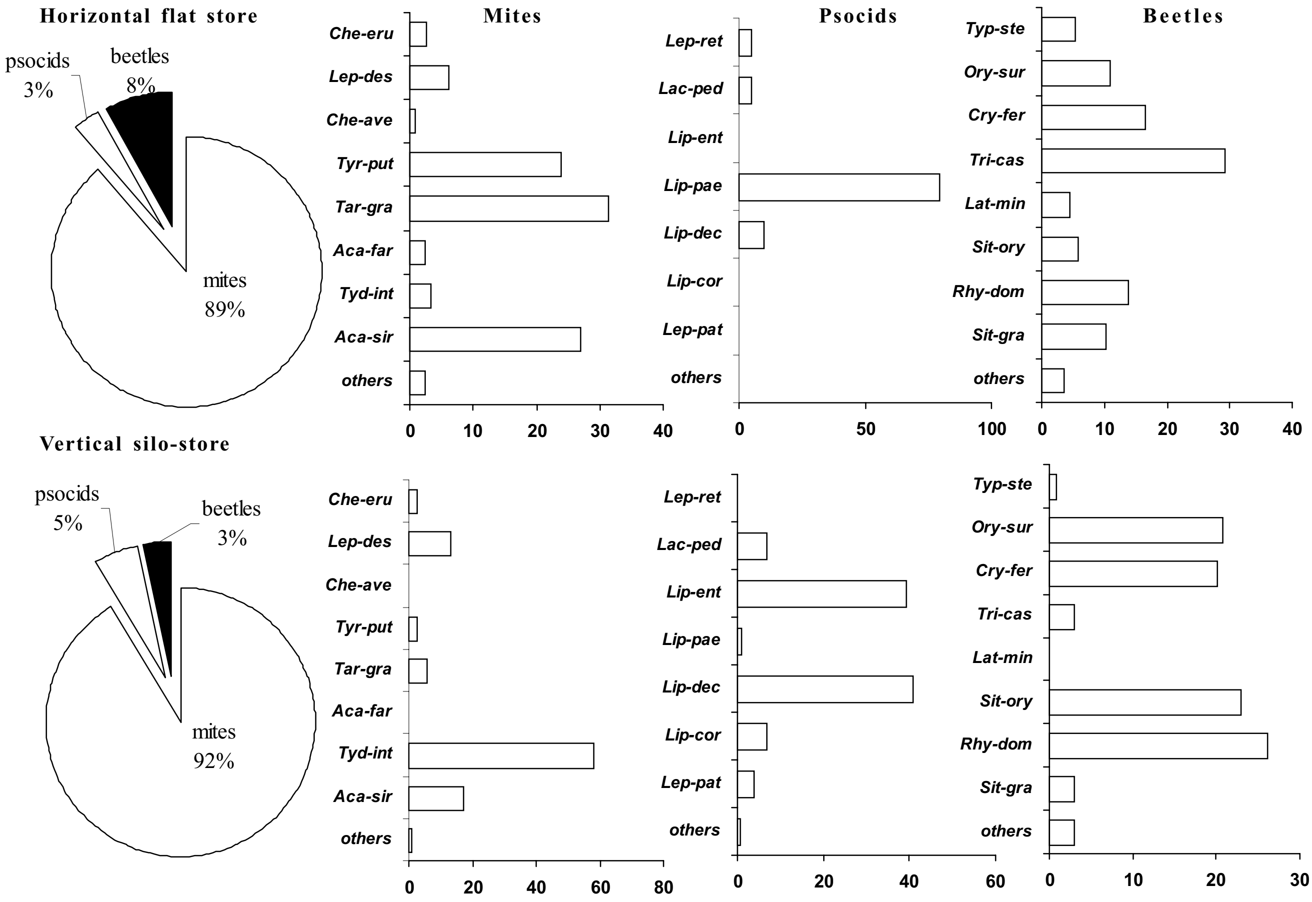

Figure 3. The dominance of arthropods groups in HFS and VSS (the pie charts show the total dominance of all arthropod groups, while the bars show species dominance in particular group)

Mites: *Che-eru*: *Cheyletus eruditus*, *Lep-des*: *Lepidoglyphus destructor*, *Che-ave*: *Cheyletus aversor*, *Tyr-put*: *Tyrophagus putrescentiae*, *Tar-gra*: *Tarsonemus granarius*, *Aca-far*: *Acarus farris*, *Tyd-int*: *Tydeus interruptus*, *Aca-sir*: *Acarus siro*

Psocids: *Lep-ret*: *Lepinotus reticulatus*, *Lac-ped*: *Lachesilla pedicularia*, *Lip-ent*: *Liposcelis entomophila*, *Lip-pae*: *Liposcelis paeta*, *Lip-dec*: *Liposcelis decolor*, *Lip-cor*: *Liposcelis corrodens*, *Lep-pat*: *Lepinotus patruelis*

Beetles: *Typ-ste*: *Typhaea stercorea*, *Ory-sur*: *Oryzaephilus surinamensis*, *Cry-fer*: *Cryptolestes ferrugineus*, *Tri-cas*: *Tribolium castaneum*, *Lat-min*: *Lathridius minutus*, *Sit-ory*: *Sitophilus oryzae*, *Rhy-dom*: *Rhyzopertha dominica*, *Sit-gra*: *Sitophilus granarius*

low humidity is a limiting condition for mites but not for beetles. Contrary, beetles are much more sensitive to low temperature than mites. Armitage (1984) demonstrated that the grain surface picks up atmospheric water and may permit the development of mite populations even when cooling systems in both flat stores and silos is used. Therefore, both types of stores (VSS, HFS) can hardly prevent the mite and psocid infestation using an active aeration or ventilation only. The complete control of surface population of mites can be achieved by treatment of the ever-wet grain surface by chemical or abrasive pesticides as proposed by Cook and Armitage (2002) or by introduction of the biocontrol agent *Cheyletus eruditus* (Žďárková 1998a). Armitage et al. (1994) noted that not only humidity but also the temperature is fluctuating in grain stores to permit the survival of insect population. Both VSS and HFS structures differ in their ability to ensure the grain and above- and inter-grain atmosphere temperature stability. Thus, it is generally more difficult to control flat stores (HFS) by fumigants, modified atmospheres and temperature than silo bins (SVV). The reason is that in HFS the air leakage is higher, open space between roof and grain surface larger and ratio of surface to volume of stored grain higher than in VSS. In addition, aeration duct system is much more complex in the HFS than VSS, and more vulnerable to damage, especially by rodents.

We can conclude that both types of stores are equally risky in terms of mite and psocid infestation probably due to difficulties to control humidity absorption in the top grain layer. However, HFS is more risky for grain storage than VSS in terms of beetle infestations of grain probably due to poorer ability to control of grain temperature and greater difficulties with the use of insecticide-fumigants in HFS than in VSS. Nevertheless, we have to stress that our (Tables 1–3) and Armitage and Lewellin's (1987) results indicate that even silo bins are not completely safe from insect pest infestation by using physical control methods only.

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ABSTRAKT

Vliv typu skladování na infestaci obilí skladištními škůdci v ČR

Skladištní škůdci působí vysoké ekonomické ztráty přímým poškozením skladovaného obilí požerem a zároveň ohrožují lidské zdraví kontaminací potravin a surovin alergeny. Cílem práce bylo zjistit, zda riziko napadení skladovaného obilí je různé v závislosti na typu skladu. Byl srovnáván stupeň infestace a druhové složení u dvou hlavních obilních skladů běžných ve střední Evropě (podlahové sklady – HFS a sila – VSS). Faunistický průzkum byl proveden celkem ve 147 obilních skladech (ČR). Bylo zjištěno, že vzorky obilí z obou typů skladů byly infestovány třemi hlavními taxonomickými skupinami členovců, a to roztoči (25 druhů, 120 000 jedinců), pisivkami (8 druhů, 5 600 jedinců) a brouky (23 druhů, 4 500 jedinců). Bylo zjištěno, že podlahové sklady a sila se lišily v druhovém složení jednotlivých taxonomických skupin (roztoči, pisivky, brouci), ačkoliv primární druhy škůdců byly zastoupeny v obou typech skladů (tj. *Lepidoglyphus destructor*, *Acarus siro*, *Tyrophagus putrescentiae*, *Lachesilla pedicularia*, *Sitophilus oryzae*, *Rhyzopertha dominica*, *Oryzaephilus surinamensis* and *Cryptolestes ferrugineus*). Jedinou výjimkou byla vyšší frekvence i abundance dvou závažných skladištních brouků (*Tribolium castaneum*, *Sitophilus granarius*) v podlahových skladech než silech. Celkový počet druhů roztočů a brouků vyskytujících se v podlahových skladech a silech byl téměř shodný. Pisivky vykazovaly vyšší druhovou diverzitu v obilních silech než v podlahových skladech. Rozdíl v celkovém počtu jedinců roztočů a pisivek (tj. průměrný počet jedinců na 1 kg obilního vzorku) zjištěných v obou typech skladů nebyl signifikantní, na rozdíl od brouků, u nichž byl zjištěn dvojnásobný počet jedinců v obilních vzorcích z podlahových skladů než ze sil. Z výsledků vyplývá, že oba typy skladů byly stejně rizikové z hlediska napadení skladištními roztoči a pisivkami, kdežto z hlediska výskytu skladištních brouků byly rizikovější podlahové sklady. Na druhou stranu však nelze sila v žádném případě pokládat za bezpečná před skladištními škůdci. Mikroklimatické podmínky (vlhkost, teplota) obou typů skladů jsou diskutovány ve vztahu k výskytu skladištních škůdců.

Klíčová slova: potraviny; obilí; skladování; sila; podlahové sklady; skladištní škůdci; roztoči; pisivky; brouci

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