

Mites associated with stored products in Greece

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Abstract A faunistic survey of mites was conducted in many product stores during a 6-year study period, 2000–2005, in Greece. A total of 1,073 samples were taken from 34 Greek counties. The survey was carried out on grains (wheat, maize, oat, barley), flour, bran, manufactured agricultural foodstuffs, dried fruits (figs, raisins), residues and dust, stored in varying quantities in five types of storage facilities (stores of agricultural cooperative unions, farm stores, commercial stores, flour mills and silos). Dominance-frequency analysis and redundancy analysis (RDA) were used to reveal the preferences of the collected taxa. Approximately 55% of the samples contained mites and 65 mite taxa were identified, belonging to 15 families in four orders. Six species, namely, *Acarus gracilis* Hughes, *A. immobilis* Griffiths, *Caloglyphus oudemansi* (Zachvatkin), *Suidasia medanensis* Oudemans, *Tyrophagus perniciosus* Zachvatkin and *Klemania plumigera* (Oudemans), were new to the fauna of Greece. Five species, *Tyrophagus similis* Volgin, *Blattisocius mali* (Oudemans), *Neoseiulus barkeri* (Hughes), *Cheyletus cacahuamilpensis* Baker and *Storchia robustus* (Berlese), were recorded for the first time in stored products in Greece. *Lepidoglyphus destructor* (Schränk), *Tyrophagus putrescentiae* (Schränk) and *Acarus siro* L. were dominant or intermediate in all storage facilities examined. *Cheyletus malaccensis* Oudemans was the most common predatory mite. The highest percentage of infestation (65.3) was recorded in the samples from stores of agricultural cooperative unions. Residue-type materials had the highest degrees and percentages of infestation.

Keywords Stored-product mites · Grains · Storage facilities · Dominance · Frequency · RDA · Dust · Residue

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Introduction

Insects, mites and rodents are the major pests of stored agricultural products. It is well documented that insects (Coleoptera, Lepidoptera and Psocoptera) and mites are the most damaging pests associated with stored grains. The degree of a product's infestation depends on the pests involved, the environmental conditions (e.g. temperature and moisture content), how the product is stored and the degree of proper hygiene conditions. The type of storage technology applied is considered a serious abiotic factor influencing the stored-grain quality (Stejskal et al. 2003).

Studies intended to record the mites infesting stored agricultural products have been conducted in several regions throughout the world (O'Farrell and Butler 1948; Zdarkova 1967, 1979, 1998; Cusack et al. 1975; Jeffrey 1976; Pagliarini 1979; Saleh et al. 1985; Corpuz-Raros et al. 1988; Mahmood 1992; Emmanouel et al. 1994; Franz et al. 1997; Long-shu and Qing-Hai 1997; Thind and Clarke 2001; Stejskal et al. 2003; Kucerova and Horak 2004; Hubert et al. 2006). Although some general trends can be seen, data from one study may not be comparable with others and generalizations are often problematic.

Although European Union and USA administratives dictate a zero or near-zero tolerance level for mite infestation in stored products (Krizkova-Kudlikova et al. 2007), the problem of stored-product mites of various agricultural commodities still exist. Mites can seriously reduce the quality and quantity of stored agricultural products. They cause not only a direct weight loss in food materials, but they also seriously reduce the viability of seed stocks, as their attack is mainly confined to the embryo (Zdarkova 1996). In wheat grains mites destroy mostly the germ and only exceptionally the endosperm (Solomon 1946). Moreover, the stored product may acquire an odor due to lipid secretions by mites. Stored-product mites cause serious economic losses by feeding on stored grain and endanger the public health by contamination of food with allergens. Several studies demonstrated that storage mites caused symptoms of bronchial asthma, allergic rhinitis and conjunctivitis, particularly in rural occupational environments (Blainey et al. 1989; Iversen and Dahl 1990). There is increasing evidence that human health can be affected by the ingestion of mites and/or their by-products (Scala 1995). Mites also serve as vectors for several kinds of moulds and bacteria (Zdarkova 1967; Hubert et al. 2003). Under favorable conditions, mites, whether fungivorous, granivorous, predators or parasites, may reach high densities, capable of causing direct or indirect damage (Sinha 1973).

Although many studies are available about the occurrence of other pest categories of stored products (e.g. insects), information about mites is still inadequate. Previous studies in Greece have indicated that mites were dominant in raw stored grains during the entire year (Athanasassiou et al. 2001, 2003; Palyvos and Emmanouel 2006). The objective of our present investigation was to study the composition of the mite species occurring in different types of storage facilities, in the framework of a large-scale survey in Greece.

Materials and methods

Sampling started at the beginning of 2000 and was completed at the end of 2005. Samples were collected from 34 counties in Greece. These samples included a great variety of stored agricultural products from the following types of storage facilities (in parentheses the abbreviation of store type and the number of stores): i. stores of agricultural cooperative unions (ACUs, 17), ii. farm stores (FARMs, 49), iii. commercial stores (COMs, 22), iv. flour mills (MILLS, 9), and v. silos (SILOs, 12). A total of 1,073 sub-samples were examined from

the following groups of stored products (in parentheses the abbreviation of each group and the number of sub-samples): 1. animal fodder (maize, wheat, barley, oats, straw, clover) (FODDERS, 498), 2. flour and bran (wheat, maize) (FLOURS, 156), 3. edible products (grains, legumes, dried fruits, cheese) (EDIBLE, 67), 4. various other products (seeds as propagules, cotton fiber etc.) (OTHERS, 51), and 5. residues and dusts (RESIDS, 301).

Sampling equipment

A plastic cylindrical receptacle of 300 ml capacity was used for obtaining samples from animal fodder, flour and seeds. Sampling of straw, clover, etc., was conducted by hand. Samplings of cheese products, from cooling rooms in cheese-dairies and supermarkets, was conducted by scraping off part of the surface of the products with a knife. A small broom and a dustpan was used for the collection of residues from agricultural products and dust from the floors and the corners of the stores.

Sampling procedures

The sampling procedures were modified according to the type of material, its quantity and the type of storage facility. Samples of bulk grain were taken from the surface of the bulk. In bins and silos, samples were taken in the upper grain layer via the hatch at the top. Where grain, flour, legumes etc. were stored in sacks, a sample was taken from the top 20 cm of the product.

The samples weighed from 25 to 250 g according to the product. Each sample was placed into a plastic bag, labeled with the origin of its collection and the type of the product's storage. The samples were transferred to the laboratory and examined as soon as possible. The Berlese–Tullgren method was used to extract mites from the samples (Evans et al. 1961; Cusack et al. 1975). The device used was based on the 'modified Tullgren apparatus', as suggested by Haarlov (1947). This apparatus is a unit of 36 funnels based on a tiered system of strip lighting and funnel bearing shelves. Alternate shelves carried four 60-W strip lights as heat source. The heat from the light bulbs desiccated the sample, forcing the mite individuals to burrow deeper into the substrate, eventually falling into a screw-top collecting vial suspended underneath. The sample was completely dried due to the continuous effect of the lights. Each sample was then weighed in order to express the mites found as individuals/dry weight unit, which is considered the most accurate approach (Cusack et al. 1975; Emmanouel et al. 1994). The collected mites were identified using a compound research microscope.

In addition to these sampling procedures, visual inspection of all locations visited was carried out. All structures, machinery and equipment etc. were examined and the presence or absence of pests was recorded. Information was also obtained on types of structures, presence or absence of ventilating and thermistor systems, duration of storage, degree of hygiene practiced and control measures normally adopted.

Data analysis

The taxa collected were categorized using the criteria of dominance and frequency (Curry 1973; Cusack et al. 1975; Emmanouel et al. 1994). 'Dominance' indicates the percentage of individuals of a given taxon, compared with the total number of individuals of all taxa found. Hence, a given particular taxon is classified as 'dominant', 'influential' or 'recedent', if it constitutes >10, 5–10 or <5% of the total number of individuals, respectively. Similarly,

three categories are recognized for the ‘frequency’ of occurrence of a taxon in the samples: it is classified as ‘constant’, ‘accessory’ or ‘accidental’, if it occurs in >50, 25–50 or <25% of the total number of samples, respectively.

The number of taxa per store type per product was submitted to analysis of variance (ANOVA) (type III SS). Fisher’s LSD test was used for the analysis of the differences between groups based 95%-confidence ranges. Before the analysis, data were transformed according to Box–Cox procedure (Box and Cox 1964).

The data were further submitted to multivariate analysis. From an ecological point of view, abundant as well as rare species may be important and thus all were included in the analysis. For the ordination analysis the environmental variables (‘store type’ and ‘product’) were split to dummy (0–1) variables (one dummy variable for each class of each environmental variable). In order to choose between linear and unimodal ordination analysis methods, the data were preliminarily submitted to detrended canonical correspondence analysis (DCCA) and the gradient length, that measures the extent of species turnover (beta diversity) along the coordination axes, was calculated. The longest gradient value was quite short (1.42) suggesting the use of a linear gradient analysis model (PCA or RDA) (Lepš and Šmilauer 2003). Thus, the data were submitted to RDA and PCA analyses using several combinations of scaling (either inter-species correlation scaling or sample distance scaling) and transformations.

For data processing Microsoft Excel v. 2003 was used. ANOVA was conducted with XLSTAT software. Ordination analysis (calculations and biplot) was performed using CANOCO v. 4.5.

Results

Approximately 55% of the samples contained mites, of which 65 taxa in 15 families and four orders were identified (Table 1). Twenty-two taxa were in the order Astigmata, corresponding to 92.7% of the total number of the collected mites, followed by 5.7% Prostigmata, 1.3% Mesostigmata and 0.2% Cryptostigmata. Six species were new to the fauna of Greece: *Acarus gracilis* Hughes, *A. immobilis* Griffiths, *Caloglyphus oudemansi* (Zachvatkin), *Suidasia medanensis* Oudemans, *Tyrophagus perniciosus* Zachvatkin, and *Klemania plumigera* (Oudemans). Five species were recorded for the first time in stored products in Greece: *Tyrophagus similis* Volgin, *Blattisocius mali* (Oudemans), *Neoseiulus barkeri* (Hughes), *Cheyletus cacahuamilpensis* Baker, and *Storchia robustus* (Berlese).

Concerning the number of taxa, no statistical difference was found between store types ($F = 0.825$, $df = 4$, $P = 0.511$). The store type * product interaction was also not statistically significant ($P = 0.465$). Differences were found between product types ($F = 8.324$, $df = 4$, $P = 0.0001$), with ‘residues’ showing the highest number of species and ‘flour’ the lowest (Fig. 1).

Stores of agricultural cooperative unions (ACUs)

Sixty-five percent of the samples contained mites. Most samples contained infestations of <10 mites/10 g d.w., but some ‘residue’ samples had higher infestations (Table 2).

Forty-four taxa of mites were identified (Table 1). *Tyrophagus putrescentiae* (Schrank) and *Lepidoglyphus destructor* (Schrank) were ‘dominant’ and ‘accessory’ and occurred in 59 and 54 of the 213 samples, respectively. *Aleuroglyphus ovatus* (Troupeau) was ‘influential’ and ‘accidental’. The following taxa were recorded only in this type of storage facility:

Table 1 Dominance and frequency of mite taxa found in each type of storage facility

ID	Taxa	ACUs		COMMs		FARMs		MILLs		SILOs	
		Dom.	Freq.	Dom.	Freq.	Dom.	Freq.	Dom.	Freq.	Dom.	Freq.
I.	Asignata										
1	<i>Acarus gracilis</i>	0.58 R	1.41 Ac	0.02 R	0.40 Ac	0.50 R	0.42 Ac				
2	<i>Acarus immobilis</i>	0.46 R	7.51 Ac	38.36 D	9.92 Ac	0.14 R	0.42 Ac				
3	<i>Acarus siro</i>	7.83 In	6.57 Ac	1.21 R	3.97 Ac	9.23 In	4.40 Ac	25.16 D	4.29 Ac	25.87 D	3.33 Ac
4	<i>Aleuroglyphus ovatus</i>	0.05 R	0.47 Ac			4.78 R	5.44 Ac				
5	Anoetidae										
6	<i>Caloglyphus oudemansi</i>	0.01 R	0.47 Ac	0.05 R	0.79 Ac	0.14 R	0.42 Ac	0.07 R	1.43 Ac		
7	<i>Caloglyphus</i> sp.	2.59 R	5.16 Ac	0.12 R	0.40 Ac						
8	<i>Chortoglyphus lactis</i>	0.07 R	1.41 Ac	10.07 D	1.98 Ac						
9	<i>Chortoglyphus arcuatus</i>										
10	Ctenoglyphidae					0.72 R	1.05 Ac	0.43 R	2.86 Ac		
11	<i>Dermatophagoides farinae</i>	0.38 R	2.35 Ac	0.05 R	1.19 Ac	0.14 R	0.84 Ac				
12	<i>Glycyphagus domesticus</i>	0.17 R	1.88 Ac	0.05 R	1.19 Ac	0.77 R	0.84 Ac	2.23 R	4.29 Ac		
13	<i>Gohieria fusca</i>	0.11 R	2.81 Ac	0.003 R	0.40 Ac	2.65 R	2.51 Ac	4.03 R	10.00 Ac		
14	<i>Lepidoglyphus destructor</i>	26.95 D	25.40 A	37.92 D	17.46 Ac	0.43 R	0.63 Ac	6.33 In	4.29 Ac		
15	<i>Rhizoglyphus echinopus</i>	0.52 R	1.41 Ac	0.33 R	0.40 Ac	36.08 D	13.60 Ac	33.07 D	18.57 Ac	32.34 D	20.00 Ac
16	<i>Rhizoglyphus</i> sp.	0.37 R	1.88 Ac	0.45 R	1.59 Ac	0.44 R	0.84 Ac			0.17 R	1.67 Ac
17	<i>Suidasia medanensis</i>	0.07 R	1.41 Ac	0.01 R	0.40 Ac	0.23 R	1.05 Ac				
18	<i>Suidasia nesbitti</i>	3.62 R	2.82 Ac	0.09 R	1.59 Ac	0.23 R	0.21 Ac	0.86 R	1.43 Ac	0.33 R	3.33 Ac
19	<i>Tyrophagus longior</i>	0.02 R	1.41 Ac			1.08 R	1.67 Ac	0.14 R	1.43 Ac		
20	<i>Tyrophagus pemiciosus</i>	0.01 R	0.47 Ac			0.95 R	1.46 Ac				
21	<i>Tyrophagus putrescentiae</i>	47.17 D	27.70 A	8.31 In	24.21 Ac	20.09 D	15.70 Ac	14.74 D	14.29 Ac	6.14 In	18.30 Ac
22	<i>Tyrophagus similis</i>			0.04 R	1.59 Ac	0.89 R	1.05 Ac				
II.	Prostigmata										
23	<i>Acarophenax tribolii</i>	0.01 R	0.47 Ac			0.14 R	0.63 Ac				
24	<i>Acaropsis docta</i>	0.43 R	1.88 Ac	0.01 R	0.40 Ac	0.04 R	0.21 Ac	0.14 R	1.43 Ac		
25	<i>Acaropsis sollers</i>	0.01 R	0.47 Ac	0.03 R	1.59 Ac	0.72 R	2.51 Ac	0.29 R	4.29 Ac	0.33 R	3.33 Ac
26	Bdellidae	0.05 R	2.82 Ac	0.01 R	0.79 Ac	0.08 R	0.21 Ac				
27	Caligonellidae	0.08 R	1.41 Ac	0.05 R	0.79 Ac	2.48 R	1.25 Ac			0.33 R	1.67 Ac
28	<i>Chelacheles</i> sp.			0.15 R	0.40 Ac						

Table 1 continued

ID	Taxa	ACUs		COMMs		FARMs		MILLs		SILOs	
		Dom.	Freq.	Dom.	Freq.	Dom.	Freq.	Dom.	Freq.	Dom.	Freq.
29	<i>Cheletomorpha lepidopterorum</i>			0.13 R	2.78 Ac	0.12 R	0.42 Ac			1.66 R	3.33 Ac
30	<i>Cheyletus aversor</i>			0.003 R	0.40 Ac	0.10 R	0.21 Ac	0.07 R	1.43 Ac		
31	<i>Cheyletus cacahuamilpensis</i>	0.01 R	0.47 Ac					0.07 R	1.43 Ac		
32	<i>Cheyletus eruditus</i>			0.05 R	1.19 Ac	0.37 R	1.25 Ac	0.86 R	4.29 Ac		
33	<i>Cheyletus malaccensis</i>	5.08 In	16.4 Ac	0.60 R	11.90 Ac	4.86 R	12.13 Ac	1.65 R	8.57 Ac	10.28 D	15.00 Ac
34	<i>Cheyletus trux</i>	0.37 R	4.70 Ac	0.37 R	2.38 Ac	0.25 R	0.63 Ac	0.22 R	1.43 Ac		
35	<i>Cunaxa setirostris</i>			0.02 R	0.79 Ac	0.27 R	1.25 Ac			1.16 R	3.33 Ac
36	Eupodidae					0.02 R	0.21 Ac				
37	<i>Ker</i> sp.			0.003 R	0.40 Ac	0.08 R	0.42 Ac				
38	<i>Lorryia nesziyonensis</i>	0.03 R	1.41 Ac	0.04 R	0.40 Ac	0.17 R	0.42 Ac	0.36 R	2.86 Ac	0.17 R	1.67 Ac
39	<i>Lorryia</i> sp.	0.29 R	0.94 Ac	0.04 R	1.19 Ac	0.56 R	1.05 Ac			0.50 R	3.33 Ac
40	<i>Neopronematus</i> sp.					0.15 R	0.42 Ac				
41	Pseudocheyletidae					0.02 R	0.21 Ac				
42	<i>Pseudotriophydeus vegei</i>					0.08 R	0.63 Ac				
43	<i>Pymotes</i> sp.	0.07 R	0.47 Ac			0.08 R	0.21 Ac			0.17 R	1.67 Ac
44	Pygmephoridae			0.003 R	0.40 Ac						
45	Raphignathidae	0.02 R	1.41 Ac	0.02 R	1.19 Ac	0.23 R	1.05 Ac			0.17 R	1.67 Ac
46	<i>Storchia robustus</i>	0.05 R	0.94 Ac	0.01 R	0.40 Ac	0.17 R	0.63 Ac				
47	<i>Tarsonemus granarius</i>	0.43 R	1.41 Ac	0.51 R	3.57 Ac	1.30 R	2.51 Ac	0.07 R	1.43 Ac	0.17 R	1.67 Ac
48	Tenuipalpidae	0.01 R	0.47 Ac								
49	Tetranychidae	0.04 R	3.76 Ac	0.04 R	2.78 Ac	0.23 R	0.84 Ac	0.22 R	2.86 Ac	0.50 R	1.67 Ac
50	<i>Tydeus kochi</i>	0.28 R	1.41 Ac	0.06 R	1.98 Ac	0.87 R	1.05 Ac	0.50 R	1.43 Ac	0.83 R	3.33 Ac
51	<i>Tydeus</i> sp.	0.32 R	3.29 Ac	0.25 R	4.76 Ac	0.93 R	1.05 Ac	6.76 In	4.29 Ac	0.33 R	1.67 Ac
III.	Mesostigmata										
52	<i>Neoseiulus barkeri</i>	0.01 R	0.47 Ac			0.06 R	0.63 Ac			0.17 R	1.67 Ac
53	Ameroseiidae							0.57 R	1.43 Ac		
54	<i>Androlaelaps casalis casalis</i>			0.03 R	0.40 Ac	0.08 R	0.42 Ac				
55	<i>Blattisocius keegani</i>	0.18 R	4.70 Ac	0.16 R	3.97 Ac	1.59 R	2.72 Ac	0.29 R	1.43 Ac	18.41 D	10.00 Ac
56	<i>Blattisocius mali</i>	0.25 R	1.88 Ac			0.17 R	0.63 Ac				
57	<i>Blattisocius tarsalis</i>	0.70 R	3.29 Ac	0.08 R	1.59 Ac	0.89 R	2.51 Ac	0.5 R	2.86 Ac		

Table 1 continued

ID	Taxa	ACUs		COMMs		FARMs		MILLs		SILOs	
		Dom.	Freq.	Dom.	Freq.	Dom.	Freq.	Dom.	Freq.	Dom.	Freq.
58	<i>Gamasellodes</i> sp.	0.01 R	0.47 Ac			0.06 R	0.21 Ac	0.07 R	1.43 Ac		
59	<i>Kleemannia plumigera</i>	0.03 R	0.94 Ac			0.17 R	0.42 Ac				
60	<i>Kleemannia plumosus</i>			0.04 R	1.19 Ac	0.54 R	1.67 Ac				
61	Laelapidae					0.14 R	0.21 Ac				
62	Parasitidae			0.01 R	0.40 Ac	0.25 R	0.63 Ac				
63	Uropodina	0.22 R	2.35 Ac	0.08 R	1.59 Ac	0.44 R	1.05 Ac				
IV.	Cryptostigmata										
64	<i>Haplochlorionius</i> sp.	0.04 R	4.70 Ac	0.1 R	0.40 Ac	0.85 R	0.42 Ac				
65	Paleosomata					0.93 R	0.63 Ac				

Dominance: a given taxon is classified as dominant (D), influent (In) or recedent (R) if it constitutes >10, 5–10 or <5% of the total number of individuals, respectively. Frequency: a taxon is classified as constant (C), accessory (A) or accidental (Ac) if it occurs in >50, 25–50 or <25% of the total number of samples, respectively. Storage facility types: ACUs, agricultural cooperative unions; COMMs, commercial stores; FARMs, farm stores; MILLs, flour mills; SILOs, grain silos

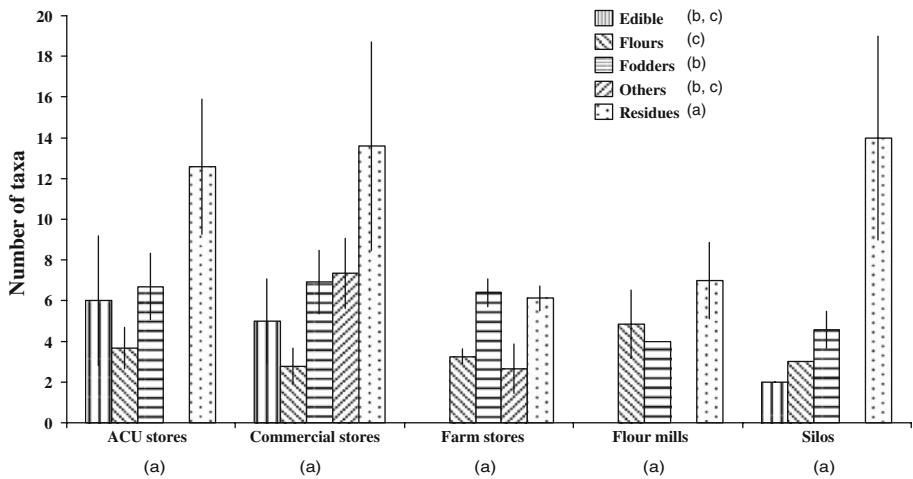


Fig. 1 The average number of taxa (mean + SE) per store type per product. Products or store types marked by the same letter do not differ significantly according to Fisher's LSD test ($\alpha = 0.05$)

Carpoglyphus lactis (L.), Anoeidae and Tenuipalpidae. *Carpoglyphus lactis* was found almost exclusively on edible products containing sugar, like dried figs and dried raisins (Fig. 2).

Farm stores (FARMS)

Fifty-one percent of the samples contained mites. In the 'residue' group 31.2% of the samples were classified into the 1–10 mites/10 g d.w. category, whereas in the 'flour' group 2.6% were classified into the 11–25 mites/10 g d.w. category (Table 2, Fig. 1).

Fifty-six mite taxa were identified (Table 1). *Tyrophagus putrescentiae* and *L. destructor* were dominant and accidental, *A. siro* was influent and accidental. *Acarus gracilis* and Ctenoglyphidae were recorded only in FARMS.

Commercial stores (COMs)

Fifty-eight percent of the samples contained mites. In the 'residue' group 19.7% of samples contained mites, with 1–10 mites/10 g d.w., whereas in the 'edible' group 14.8% contained 51–250 mites/10 g d.w. (Table 2, Fig. 1).

Forty-four taxa were identified (Table 1). *Acarus siro*, *L. destructor* and *Chortoglyphus arcuatus* (Troupeau) were dominant and accidental, *T. putrescentiae* was influent and accidental. *Chelacheles* sp. was recorded only in COMs.

Flour mills (MILLS)

Of the 70 samples collected 46% contained mites. The highest percentage of infestation was recorded in residues (68.2). In the residues 23% of samples contained 1–10 mites/10 g d.w., 9% contained 11–25 mites/10 g d.w. and 9% 26–50 mites/10 g d.w. Fewer infestations occurred in animal fodder and flour (Table 2, Fig. 1), in which 26 taxa were recorded

Table 2 Number of samples, percentage of infestation and degree of infestation of the collected samples

Storage facility	Group of stored products	Number of samples	Percentage of infestation	Degree of infestation ^A
Agricultural Cooperative Unions	Animal fodder	71	56.3	a(46.5), b(7), d(2.8)
	Flour and bran	13	61.5	a(30.8), b(15.4), c(7.7), d(7.7)
	Edible products	34	70.6	a(52.9), b(14.7), c(2.9)
	Residues	95	71.6	a(41), b(18.9), c(3.2), d(1), e(3.2), f(1), g(1), h(1), i(1)
	Total	213	65.3	
Farm stores	Animal fodder	295	44.1	a(29.8), b(12.2), c(1.7), e(0.3)
	Flour and bran	78	48.7	a(29.5), b(16.7), c(2.6)
	Various products	12	50.0	a(41.7), b(8.3)
	Residues	93	75.3	a(44.1), b(31.2)
	Total	478	51.0	
Commercial stores	Animal fodder	91	48.3	a(32.9), b(14.3), e(1.1)
	Flour and bran	24	45.8	a(29.2), b(8.3), c(4.2), e(4.2)
	Edible products	27	48.1	a(25.9), c(3.7), d(3.7), e(7.4), f(7.4)
	Various products	39	61.5	a(46.1), b(5.1), c(2.6), d(2.6), e(2.6), f(2.6)
	Residues	71	77.5	a(39.4), b(19.7), c(7), d(4.2), e(1.4), f(1.4), g(4.2)
Flour mills	Animal fodder	11	18.2	a(18.2)
	Flour and bran	37	40.5	a(29.7), b(10.8)
	Residues	22	68.2	a(27.3), b(22.7), c(9.1), d(9.1)
	Total	70	45.7	
Silos	Animal fodder	30	56.7	a(46.6), b(10)
	Flour and bran	4	50.0	a(50)
	Edible products	6	66.7	a(66.7)
	Residues	20	55.0	a(10), b(40), c(5)
	Total	60	56.7	

^A The letters indicate the level of infestation (number of mites/10 g dry weight of sample): a = <1; b = 1–10; c = 11–25; d = 26–50; e = 51–100; f = 101–250; g = 251–500; h = 501–1,000; i = 1,001–2,000 and j = >2,000. In parentheses the percentage of total samples of each group infested with mites

(Table 1). *Tyrophagus putrescentiae*, *L. destructor* and *A. siro* were dominant and accidental, *Gohieria fusca* (Oudemans) and *Tydeus* sp. were influent and accidental.

Silos (SILOs)

Fifty-seven percent of samples contained mites. In the residues 40% of samples were infested with 1–10 mites/10 g d.w. and 5% with 11–25 mites/10 g d.w. Fewer infestations occurred in the other groups of samples (Table 2, Fig. 1).

Of the 20 taxa identified, *L. destructor*, *A. siro* and the predatory mites *Cheyletus malaccensis* Oudemans and *Blattisocius keegani* Fox were dominant and accidental, *T. putrescentiae* was found to be influent and accidental (Table 1).

RDA analysis

Permutation tests, with 999 permutations, on the first canonical axis and on all axes of RDA analysis were significant ($P = 0.004$ and $P = 0.006$, respectively). However, the explained variance was quite low (8.1%) suggesting highly structured data with rather uncorrelated

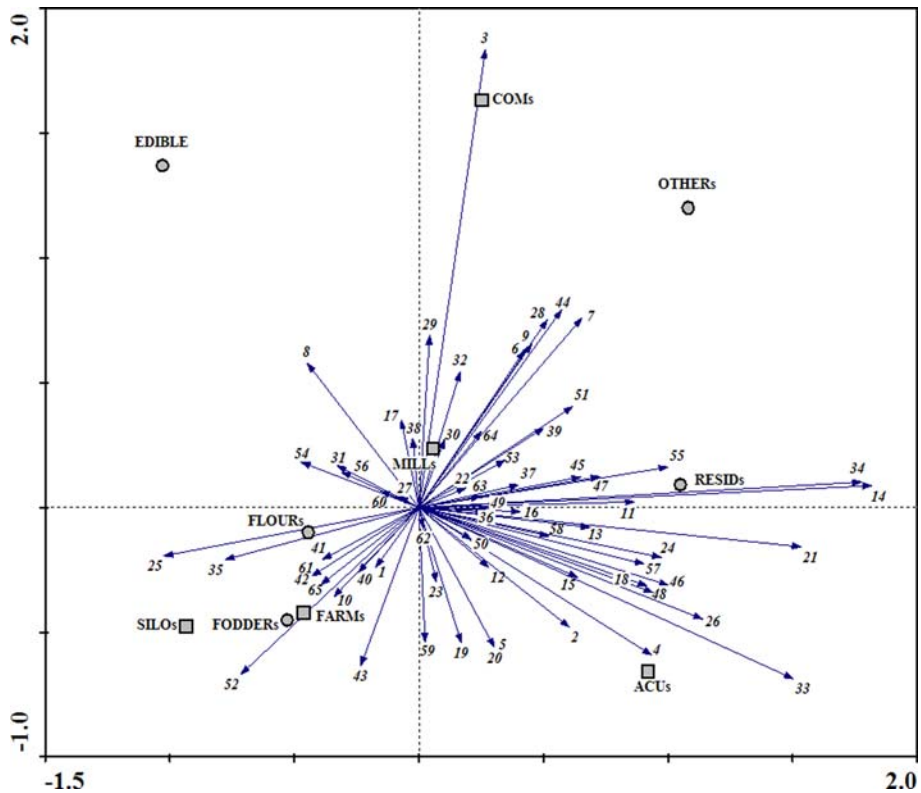


Fig. 2 Species–environment biplot diagram from redundancy analysis (RDA), summarizing the association among species (arrows) as well as between species and environmental variables (circles indicate classes of products and squares indicate classes of storage facilities). The species ID is given in Table 1

variables (taxa). The resulting diagram (Fig. 2) shows that the first principal axis is positively associated with Residues and ACUs stores and negatively associated with FLOURs and SILOs, whereas the second axis is positively associated with COMs and negatively associated with FARMs and ACUs stores. With scaling focused on the inter-sample distances, the distance between the centroids of store type and commodity classes approximates the Euclidean distance (Lepš and Šmilauer 2003). In the figure it is seen that the distances between classes of products are greater than the distances between store-type classes, indicating greater differences in species compositions between products than between store types.

By projecting the environmental variables on the species arrows we can approximate the average value of the species in the particular class of the (dummy) environmental variable. For example (in parentheses the species ID; Table 1), *C. lactis* (8) and *S. medanensis* (17) prefer edible products, whereas *A. siro* (3) is found more often in Commercial stores. *Chelacheles* sp. (28), Pygmephoridae (44), *C. arcuatus* (9), *C. oudemansi* (6) and *Caloglyphus* sp. (7) have higher relative abundance in Commercial stores and other products. The taxa projected on the lower right quarter of the plain, as well as those close to the right part of the first axis (e.g., *C. trux* Rohdendorf (34), *L. destructor* (14), *T. putrescentiae* (21), *A. docta* Berlese (24), *S. robustus* (46), *A. ovatus* (4), *A. immobilis* (2), *C. malaccensis* (33) and Bdellidae (26)) are expected to be more abundant in Residues' samples and in ACUs. *Acaropsis sollers* Kuzin (25), *N. barkeri* (52), *Pyemotes* sp. (43) and *C. setirostris* (Hermann)

(35) are expected to be more abundant in samples belonging to Silos, whereas *A. gracilis* (1), Ctenoglyphidae (10), *Neopronematus* sp. (40), Pseudocheyletidae (41), *P. vegei* Andre (42), Laelapidae (61) and Paleosomata (65) are expected to be more abundant in fodders and farms stores.

Discussion

Of the total number of samples (1,073), 55.5% contained mites, showing the extremely high mite occurrence in all types of stored products. In a similar study, Franz et al. (1997) studied 859 samples of stored products in Germany and reported 86.4% infestation. Pagliarini (1979) found 73.3% infestation in 353 samples from Croatia. Cusack et al. (1975) noted a 75.3% infestation during a study on 766 samples from Ireland. Zdarkova (1967) recorded 68.6% infestation in 389 samples from former Czechoslovakia, whereas Chmielewski (1971) reported 30% in 905 samples from Poland. Thind and Clarke (2001) studied 571 samples of cereal-based food products in UK and reported 21% of infestation. Comparing the degree of infestation in the present survey with these values, the rate of mite infestations in stored products in Greece seems to be somewhat below the European average. Perhaps this is due to Greece's warm and dry climate, because these conditions are generally suboptimal for the development of most mites.

The highest percentage of infestation was found in samples from stores of agricultural cooperative unions. Although in the majority of these facilities fumigations were often applied, the poorly conserved premises along with the lack of preventive hygiene measures, before the storage of the products, may be considered as the main reasons for the high mite presence. The lowest infestation rate was noticed in samples from flour mills, probably due to the more frequent fumigations or other insecticidal applications (e.g. structural treatments), and the more intensive hygiene measures, compared with other storage facilities. Still, the high mite numbers in the residues clearly indicate their importance as infestation sources.

During the course of the survey 65 taxa of mites were collected, although identification to the species level was not always possible. In previous surveys Franz et al. (1997) in Germany recorded 49 taxa, Long-shu and Qing-Hai (1997) in China 79 taxa, Mahmood (1992) in Iraq 16 taxa, Corpuz-Raros et al. (1988) in Philippines 65 taxa, Saleh et al. (1985) in Egypt 33 taxa, Pagliarini (1979) in Croatia 23 taxa, Cusack et al. (1975) in Ireland 70 taxa, Zdarkova (1967, 1998) in former Czechoslovakia 41 and 32 taxa, respectively, and O'Farrell and Butler (1948) in Northern Ireland recorded 62 taxa. In Greece, in earlier surveys of a more limited geographical extent, Emmanouel et al. (1994) recorded 17 taxa, Palyvos et al. (2002) 37 taxa, and Papaioannou-Souliotis (1991) found 28 taxa of mites in house dust. Eliopoulos and Papadoulis (2001) reported five new records of cheyletid mites from stored products.

The highest number of taxa was found in samples from farm stores, but most FARMS samples had low infestation levels. These findings are consistent with those of Emmanouel et al. (1994), where most taxa had been found in the farm stores too. The highest degree of infestation was noticed in samples from stores of agricultural cooperative unions and commercial stores, where most products are stored in sacks. According to O'Farrell and Butler (1948) and Cusack et al. (1975), bagged stored products present a larger surface area and permit a greater increases in moisture content, consequently they allow faster mite development. In a grain column, aeration and other climatic conditions are suitable for mites only

in the highest zone of the bulk, and thus in such stored-grains more mites occur at the upper layer than at deeper layers (Athanassiou et al. 2003; Palyvos and Emmanouel 2006).

The highest percentages and the highest degrees of infestation were found in residue-type materials. These samples usually contained residues of products mixed with dust, collected from the floors and the corners of stores. The residues are usually in contact with the ground, and therefore have a higher moisture content than the samples from other parts of the stores, providing improved conditions for mite growth (Sinha 1979). Infested residues are an important source of mites for adjacent stored products. This is consistent with earlier findings of mites in residues (Cusack et al. 1975; Pagliarini 1979; Emmanouel et al. 1994; Zdarkova 1998; Palyvos et al. 2002).

Astigmatid mites were the most numerous in the current study, with 22 taxa found. *Lepidoglyphus destructor* (Glycyphagidae) was dominant in all five types of storage facilities and it was accessory in the stores of agricultural cooperative unions. Many researchers believe that this species can develop high densities, similar to *A. siro*, although the former is of less economic importance (O'Farrell and Butler 1948; Cusack et al. 1975). *Lepidoglyphus destructor* seems to be quite noticeable and common in Greek stores, according to previous studies (Emmanouel et al. 1994; Palyvos et al. 2002). *Gohieria fusca* of the same family was influent only in flour mills.

Tyrophagus putrescentiae was recorded either as dominant or as influent in each type of storage facility examined, whilst it was both dominant and accessory in stores of agricultural cooperative unions. This species is found in an extremely large variety of commodities with high fat and protein contents (Hughes 1976). In Spain it is considered to be an important pest of dry-cured ham where it feeds on the surface layer (Arnau and Guerrero 1994; Garcia 2004). This species can develop at higher temperatures than other stored-product astigmatids (Sinha and Watters 1985; Sinha 1991) and it is very common in Greek storage facilities (Emmanouel et al. 1994; Palyvos et al. 2002).

Acarus siro was found in three out of five types of storage facilities as dominant, and only in one as influent. It is a major pest of stored grains in the temperate regions of the world (Hughes 1976). Its occurrence is considerable in Greece as well, but at a lower level in comparison with other central and northern European countries. This may be attributed to the warm and dry Greek climate that negatively affects its development (Emmanouel et al. 1994). In the present study this species developed population densities of over 200 mites per 10 g of dry sample weight, especially in stored cheese in cooling rooms.

Aleuroglyphus ovatus (Acaridae) was influent in the stores of agricultural cooperative unions. Exposure to this mite may cause allergy, especially important for workers in the grain industry (Geary et al. 2000).

Twenty-nine prostigmatid taxa were found, mostly belonging to the Cheyletidae (10 taxa) and Tydeidae. *Cheyletus malaccensis* was the most common cheyletid, accounting for 75.4% of all individuals of the Cheyletidae. In fact, this species was recovered from all categories of storage facilities, being dominant in silos and influent in stores of agricultural cooperative unions. This species feeds not only on pest mites but also on insect eggs (Rizk et al. 1979; Yousef et al. 1982) and it is associated with both grain mass and grain residues (Hubert et al. 2006). In the present study *C. eruditus*, common in central and northern Europe (Hubert et al. 2006; Lukas et al. 2007), was found in much lower numbers.

Twelve Mesostigmata taxa were found, of which *Blattisocius keegani* (Ascidae) was present in all five storage types and dominant in the silos. Only two Cryptostigmata taxa were found, whose occurrence was considered recedent and accidental.

Summarizing, one of the most significant findings of this survey was the relatively high percentage of infestation of a wide range of stored products, despite the relatively dry and

warm Greek climate. Many mite species were found. The survey emphasizes the importance of mites in stored products, information that may aid in understanding and preventing economic losses caused by mite contamination of stored agricultural products.

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