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Mite community of storage facilities in Iran

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Summary

The density of mite populations in storage facilities in Iran was investigated by sampling three silos and three flour-mills during autumn 1997. Low mite density values were found, which might be attributed to insecticide use and short-term storage. In addition, a substantial spatial variation in abundance measured from numerical stability in the most common taxa was detected. However, although abundance was low and varied, and distribution was substantially disordered, spatial patterns remained sufficiently stable to show trends at the community level. For instance, mite assemblages were quite similar in their functional structure since predators were numerically dominant in 12 assemblages out of 16 surveyed in grain and refuse. As well, the study of community composition using correspondence analysis revealed that climate is probably the main source of mite community variability in storage facilities.

Key-words: abundance, community composition, correspondence analysis, nested-subset analysis, spatial variation

Résumé

La densité des populations d'acariens peuplant des installations d'entreposage en Iran a été étudiée à partir d'un échantillonnage réalisé dans trois silos et trois minoteries au cours de l'automne 1997. De faibles valeurs d'abondance ont été enregistrées et ceci pourrait résulter de l'utilisation des insecticides et d'un stockage de courte durée. De plus, une mesure de stabilité numérique chez les espèces les plus communes a révélé une forte variation spatiale des densités. Toutefois, malgré une abondance faible et hétérogène et une distribution globalement désordonnée, certaines caractéristiques spatiales se sont avérées suffisamment stables pour que des tendances puissent être dégagées à l'échelle de la communauté. Ainsi, les assemblages d'acariens apparaissent peu différents dans leur organisation fonctionnelle dans la mesure où les prédateurs dominent numériquement dans 12 des 16 assemblages examinés dans les grains et les déchets. De même, l'étude de la composition du peuplement par l'analyse des correspondances montre que le climat est probablement le principal responsable de la variabilité décelée dans la communauté d'acariens des installations d'entreposage.

Mots-clés: abondance, analyse des correspondances, analyse des sous-ensembles emboîtés, composition du peuplement, variation spatiale

Introduction

A central problem in ecology is to understand how communities are organized with respect to species abundances, species number and species composition (e.g. KODRIC-BROWN & BROWN, 1993; WORTHEN, 1996). Most studies have been directed at how local and regional, abiotic environmental conditions and biotic interactions contribute to community organization (review in TILMAN, 1982). Yet the specific contribution of each of these factors generally remains unknown because of the complexity of their interactions (DRAKE, 1990; IVES & KLOPFER, 1997). Some conceptual models predict that the importance of interactions between structuring factors should decrease with stochastic effects, notably with abiotic disturbance (BERTNESS & CALLAWAY, 1994; CHESSON & HUNTLY, 1997).

In storage facilities, mite granary community appears able to conserve its species richness despite repeated application of biocides (WHITE & SINHA, 1990; PRICKETT & MUGGLETON, 1991). In such facilities, mites also colonize neglected materials such as dust, broken grain and small pieces of straw differing from the grain in physical structure and the lack of chemical control (hereafter referred to as refuse), taken from floors and recesses. Despite these differences, mite assemblages in refuse show a certain similarity in species composition with assemblages found in the grain (e.g. CUSACK *et al.*, 1976; PAGLIARINI, 1979; ARDESHIR *et al.*, 2000).

By contrast, climate has proven to be significant factor in understanding spatial variation in the abundance of mite species (NORRIS, 1958; SINHA, 1968; BURRELL & HAVERS, 1976; ARMITAGE, 1984). Thus, there is a need for a formal examination of the relative importance of climate and biocides on mite community organization in storage facilities. Given the lack of prior knowledge about mite granary community in Iran, the logical step was a descriptive study. Our objectives were thus (1) to quantify species abundance and species number in six storage facilities (silos and flour-mills), (2) to investigate spatial variation of abundance for the most common taxa, and (3) to analyze community organization from predominant patterns in mite community assembly.

Materials and methods

This study was a preliminary investigation of granary community of mites in northern Iran, where temperate climatic conditions prevail (GANJI, 1960, 1968). Some of the largest grain stores in the country are located in this region. The survey was conducted during October 1997 in three concrete silos and three concrete flour-mills from the provinces of Mazandaran, Golestan and Teheran. Silos were chosen for their high capacity of storage: (i) 110,000 tons for silo S_1 located in the village of Neka (36°39'N, 53°19'E); (ii) 16,000 tons for silo S_2 located in the town of Gorgan (37°00'N, 54°30'E); and, (iii) 80,000 tons for silo S_3 situated in the outskirts of Karaj (36°00'N, 51°00'E) The flour-mills were chosen for their proximity to the silos. The Memarian F_{1A} and Rezay F_{1B} flour-mills (3,000 tons and 7,000 tons, respectively) were located in the town of Sari, near the Neka silo. The Tolou F_2 flour-mill (20,000 tons) was situated in the outskirts of Gorgan. Grain stored in each facility had been regularly treated with malathion, pirimiphos-methyl or aluminum phosphide, in order to maintain storage pest infestation at a commonly accepted level. Grain debris and straw in each flour-mill were assembled and stored in 50 or 100-kg sacks, which appeared not to be controlled.

In view of the existence of such a number of large silos and flour-mills in the region, the sampling was aimed at favoring the number of sites rather than the number of locations within the sites. For technical reasons, measure of temperature and ambient grain moisture content could not be performed. Data on macroclimatic conditions were obtained from nearby weather stations. For instance, in October 1997, mean monthly values of temperature and relative humidity for Mazandaran (S_1, F_{1A}, F_{1B}), Golestan (S_2, F_2) and Teheran (S_3) were 21°C, 24°C, 23°C and 79%, 68%, 36%, respectively.

Data on the mite fauna were collected from a total of 16 samples of wheat grain and refuse: nine samples from silos, namely in each silo, grain harvested in Iran (labelled as S_{1l}, S_{2l} and S_{3l}), grain imported from Australia and Canada (S_{1i}, S_{2i} and S_{3i}) and dust accumulated in hiding places or on exterior ledges in the silo buildings (S_{1d}, S_{2d} and S_{3d}); and, seven samples from flour-mills, namely in each flour-mill, grain produced in Iran (labelled as F_{1Al}, F_{1Bl} and F_{2l}), and in flour-mills F_{1A} and F_{1B}, small sized fragments of grain (F_{1Ar} and F_{1Br}) and chaff (mainly glumes and small pieces of straw) put in bags (F_{1Ac} and F_{1Bc}). Each sample was composed of five sub-samples of about 100 g taken randomly and close to each other (in grain bulk at a depth of around 20 cm in the three silos and in the flour-mill F_2, and inside bags of 100 kg in flour-mills F_{1A} and F_{1B}).

Extraction of mites was made by means of modified BERLESE-TULLGREN funnels except for grain dust for which a flotation technique was used (HART & FAIN, 1987). Some of the mite species (i.e. pyroglyphids) found in this habitat do not clearly show a negative phototropism. In the case of BERLESE-TULLGREN funnels, the efficiency of mite extractions was verified by opening and examining the inside of 100 damaged grains in each sample. No mite was found in any grain. Specimens extracted from the five sub-samples in each sampling location were pooled in order to express density as the number of mites per 500 g of material. All extracted mites were sorted to species and, in some cases, to family.

Species were allocated to one of the following feeding categories: predators of mites; fungivores; granivores; saprophagous mites; and, parasites of insects, taking into account that this allocation is not necessarily exclusive as an organism may belong to more than one functional group over its lifetime. Although astigmatid mites are known to have a relatively wide dietary range due to their fungal associations (SINHA, 1963; SINHA & WALLACE, 1966; SINHA *et al.*, 1969; OCONNOR, 1982, 1984), their allocation to groups 2-4 was based on data available in the literature (SINHA, 1963, 1979; HUGHES, 1976; KRANTZ, 1978, GUEYE-NDIAYE & FAIN, 1987; HOUCK & OCONNOR, 1991).

Spatial variation of abundance was quantified using the stability index of HANSKI & KOSKELA (1978) ($SI = 2 \mid p_j - p_k \mid / (p_j + p_k)$ for $p_j + p_k > 0$, where p_j and p_k are the proportion of individuals for the j^{th} and k^{th} sampling locations occupied by a taxon, respectively). For each taxon a value for the total stability (SI_m) was then estimated as the average of the stability over all paired locations. Taxa with SI_m lower than unity ($0 \leqslant SI_m \leqslant 1$) can be regarded as numerically stable in sampling locations whereas those with SI_m higher than unity ($1 < SI_m \leqslant 2$) can be considered as numerically unstable.

Nested-subset analysis of species composition was conducted using the "Nestedness Temperature Calculator Programme" available on the Internet site of AICS Research, Inc. (ATMAR & PATTERSON, 1995; WRIGHT *et al.*, 1998).

Community analysis was performed using correspondence analysis (CA). This method is a form of principal component analysis that involves a double standardisation of census or presence/absence data (usually CA is repeated using presence/absence data to account for possible artifacts due to sampling method). In this instance, CA serves to extract a small number of axes, along which sampling locations will be ordered so as to summarise preponderant patterns in mite community assembly. This ordination corresponds to an indirect gradient analysis (e.g. TER BRAAK, 1985; LEGENDRE & GALLAGHER, 2001).

Results

A total of 4,342 individuals belonging to 24 mite taxa were collected during the survey of storage mites in northern Iran. A comparative overview of densities and species number of mite assemblages is given in table 1. In total, 1,857 individuals of 19 taxa were collected from silos, and 2,485 individuals of 16 taxa from flour-mills, whereas 11 taxa were shared in common. Overall number of individuals recorded in grain locations in flour-mills was higher than in grain locations in silos, with one exception (sampling location S_{2i}; table 1). In addition, the average number of taxa per grain location was greater in flour-mills (8.3; range 8-9) than in silos (5.8; range 4-8). By contrast, mean overall abundance was significantly

Table 1 — Density per 500 g and characteristics of assemblages of mites in wheat grain and refuse sampled in silos and flour-mills in Iran during October 1997. Species are arranged according to functional groups. Diversity (H') was measured by the Shannon-Weaver index, as $H' = -\Sigma p_i \ln p_i$, and the evenness component of diversity, by the Pielou index, as $J' = H' / \ln S$, where S is the total number of taxa. Proportional representation of predatory and fungivorous mites in species number and abundance is also given. S_1, S_2, S_3, silos of Neka, Gorgan and Karaj, respectively; F_{1A}, F_{1B}, F_2, Memarian, Rezay and Tolou flour-mills, respectively; l, locally produced grain; i, imported grain; d, organic dust; r, grain debris; c, chaff.
* = no dominant role of predatory mites or sub-dominant role of fungivorous mites.

	Silo 1			Silo 2			Silo 3			Flour-mill 1A			Flour-mill 1B			Flour-mill 2
	S_{1l}	S_{1i}	S_{1d}	S_{2l}	S_{2i}	S_{2d}	S_{3l}	S_{3i}	S_{3d}	F_{1Al}	F_{1Ar}	F_{1Ac}	F_{1Bl}	F_{1Br}	F_{1Bc}	F_{2l}
Predatory mites																
1. *Cheyletus malaccensis* Oudemans, 1903	40	48	36	21	241	30	6	–	–	127	64	144	33	383	350	251
2. *Acaropsellina sollers* (Kuzin, 1940)	–	–	–	2	–	7	37	65	90	–	–	–	–	–	–	–
3. *Zachvatkiniola reticulata* (Cunliffe, 1962)	4	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
4.. *Nodele calamondin* Muma, 1964	–	–	–	2	–	198	–	–	–	–	–	–	–	–	–	–
5. Caligonellidae	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
6. *Cheletomorpha lepidopterorum* (Shaw, 1794)	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–
Fungivores																
7. *Tyrophagus putrescentiae* (Schrank, 1781)	–	4	3	5	12	–	3	4	–	21	15	1	7	6	–	1
8. *Lepidoglyphus destructor* (Schrank, 1781)	2	3	27	–	1	4	–	–	–	13	3	10	3	–	18	16
9. *Caloglyphus berlesei* (Michael, 1903)	–	–	–	–	–	–	–	–	–	–	3	2	39	4	–	1
10. *Cosmoglyphus oudemansi* (Zachvatkin, 1937)	–	–	–	–	–	–	–	–	2	–	4	4	34	244	–	–
Granivores																
11. *Aleuroglyphus ovatus* (Troupeau, 1878)	–	2	–	2	–	–	–	–	–	1	7	–	11	29	10	1
12. *Acarus siro* Linneaus, 1758	11	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–
Saprophagous																
13. *Suidasia nesbitti* Hughes, 1948	2	–	–	4	10	–	3	2	3	1	–	4	–	207	–	–
14. *Dermatophagoides farinae* Hughes, 1961	–	2	873	–	–	5	–	2	10	–	8	1	–	160	–	1
15. *Chortoglyphus arcuatus* (Troupeau, 1879)	–	2	–	–	–	–	–	–	–	–	–	–	–	–	11	–
16. *Blomia freemani* Hughes, 1948	–	–	–	2	–	–	–	–	–	–	–	–	–	–	–	–
17. *Goheria fusca* (Oudemans, 1902)	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–
Parasites of insects																
18. *Pyemotes herfsi* Oudemans, 1936	–	–	2	–	–	–	–	–	–	1	–	2	–	–	8	–
Unidentified																
19. Tydeidae	–	–	–	–	1	7	–	–	–	–	157	–	10	1	–	5
20. Uropodidae	–	–	9	–	–	–	–	–	–	12	1	5	1	13	10	–
21. Tarsonemidae	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
22. Laelapidae	–	–	–	–	–	–	–	–	–	2	–	–	–	1	–	–
23. Stigmaeidae	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
24. Tenuipalpidae	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1
Number of taxa	8	6	6	7	5	6	5	4	4	8	9	9	9	11	6	8
Number of individuals	64	61	950	38	265	251	50	73	105	178	262	173	139	1049	407	277
H'	1.27	0.85	0.38	1.45	0.39	0.78	0.89	0.46	0.53	1.00	1.21	0.76	1.74	1.54	0.62	0.43
J'	0.61	0.48	0.21	0.74	0.24	0.44	0.55	0.33	0.38	0.48	0.55	0.35	0.79	0.64	0.35	0.21
Predators/others																
numbers of taxa	0.60	0.20	0.20	0.75	0.25	1.00	0.66	0.33	0.33	0.14	0.13	0.12	0.29	0.10	0.20	0.14
numbers of individuals	2.55	3.69	0.04*	1.92	10.04	15.66	6.14	8.25	6.00	2.49	0.32*	4.50	0.32*	0.57*	6.14	9.65
Fungivores/others except predators																
numbers of taxa	0.25	0.66	0.66	0.33	1.00	0.50	0.50	0.50	0.50	0.40	1.00	1.00	1.33	0.43	0.25	0.75
numbers of individuals	0.12*	1.16	0.03*	0.63*	1.18	0.33*	0.75*	1.00	0.15*	2.00	0.14*	1.58	3.77	0.62*	0.46*	2.25

lower in grain than in refuse, whereas there was no significant difference in the mean number of taxa (average value ± SE : for abundance, 127 ± 31 and 457 ± 145 in grain and refuse, respectively; for number of taxa, 6.4 ± 0.6 and 7.3 ± 0.9 in grain and refuse, respectively) (MANN-WHITNEY *U*-tests: for abundance, $U = 80.0$, $n_1 = 9$, $n_2 = 7$, $p = 0.03$; for number of taxa, $U = 66.5$, $n_1 = 9$, $n_2 = 7$, $p = 0.49$).

Numerical stability was investigated for the 11 taxa (nos. 1, 2, 7, 8, 9, 10, 11, 13, 14, 19 and 20 in Table 2) with suitable frequency of occurrence (i.e. a frequency > 50% of corresponding sampling locations) at the scale of all the locations studied or at a smaller scale (i.e. the sampling locations in silos S, in flour-mills F, in S grains or in F grains; see Table 1). No taxon could be regarded as numerically stable ($SI_m < 1$) at a large scale of investigation. Yet, at a smaller scale, two species were numerically stable: *Cheyletus malaccensis* (no.1) when all F sampling locations are taken into account, and *Lepidoglyphus destructor* (no. 8) where grain locations in flour-mills F_{1Al}, F_{1Bl} and F_{2l} are concerned. All the other taxa were numerically unstable or even strongly unstable when SI_m was higher than the average value measured for a given set of sampling locations (for instance, species no.14 in which SI_m was 1.762, 1.765 and 1.826 at a large scale, in all S sampling locations and in all F sampling locations, respectively). Overall mean numerical stability was not significantly different between silos and flour-mills as well as between S grains and F grains (average value ± SE: 1.55 ± 0.09, 1.47 ± 0.11, 1.43 ± 0.16, 1.43 ± 0.15, for all S sampling locations, all F sampling locations, S grain locations and F grain locations, respectively) (MANN-WHITNEY *U*-tests: for silos and flour-mills, $U = 48.0$, $n_1 = 6$, $n_2 = 9$, $p = 0.95$; for S grains and F grains, $U = 33.0$, $n_1 = 5$, $n_2 = 7$, $p = 1.00$).

No pattern of stability-density dependence was detected at any level of investigation. By contrast, where both all sampling locations and F sampling locations were concerned, taxa collected in a large number of locations tended to be more stable than taxa found in a small number of locations (SPEARMAN's $r_s = -0.975$, $p < 0.05$, $n = 5$, and -0.940, $p < 0.005$, $n = 9$, respectively). As the number of locations occupied by taxa can be regarded as a measure of their habitat resource use, these results indicate a certain degree of habitat specialization in the most frequent taxa within storage facilities (HANSKI & KOSKELA, 1978).

Although species composition as well as diversity and the evenness component of diversity (Table 1), which reflect the species-density relationships in sampling locations, varied substantially, the functional structure of assemblages did not differ very much. Indeed, the ratio predatory mites/other mites accounted for the numerical dominance of predators in most of the assemblages (with the exception of the location F_{1Bl} for the grain, and locations S_{1d}, F_{1Ar} and F_{1Br} for refuse) even though the number of species of predatory mites was nowhere higher than that of other mites. Similarly, a numerical sub-dominance of fungivorous mites was observed in silos except for those containing the local grain. The number of exceptions (indicated by an asterisk in table 1) increased notably in refuse where only the assemblage F_{1Ac} had such a sub-dominance pattern.

On the other hand, patterns of species composition at the scale of both storage facilities (Fig. 1A) and sampling locations (Fig. 1B) did not square statistically with non-random patterns termed "nestedness" (e.g. ATMAR & PATTERSON, 1993). This result contrasts with that obtained for a lot of animal and plant communities (WRIGHT *et al.*, 1998). Yet it does not mean that mite community assembly is intrinsically indeterministic but it points to

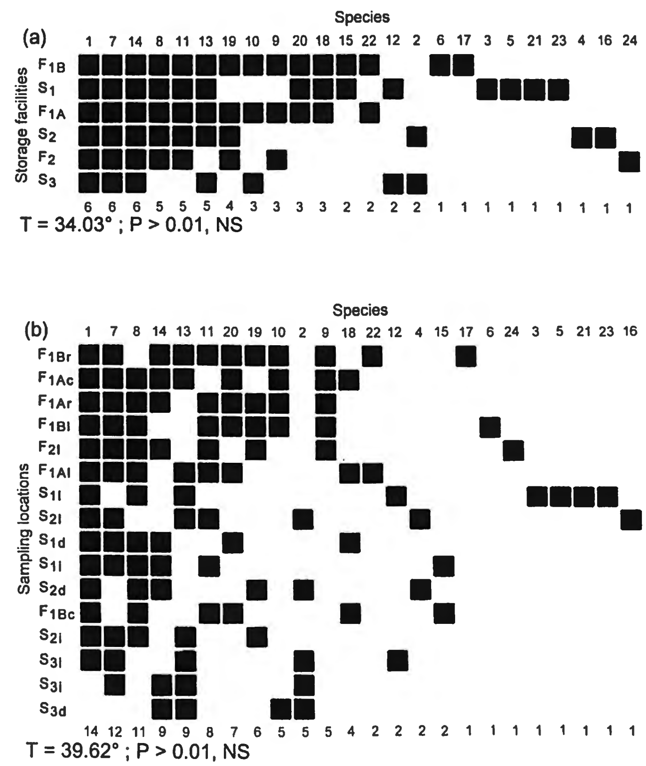

Fig. 1 — Occurrence of mite taxa (black square, presence; white square, absence) in (a) six storage facilities and in (b) 16 sampling locations surveyed in Iran. The matrices are constructed from storage facilities and sampling locations arranged in order of decreasing species number and from taxa ranked in order of decreasing number of incidences. The metric T measures the "heat of disorder" in data matrices (ATMAR & PATTERSON, 1993, pp. 373-374). It ranges from 0° for a perfectly cold, most ordered matrix to 100° for a maximally hot, most disorderd matrix. P is the Monte Carlo-derived probability that the matrix was randomly generated (500 trials). As P values were definitely higher than the critical level of 0.01 (WRIGHT *et al.*, 1998, p. 4), mite community at both scales of investigation was found to have no significant nested structure (i.e. to have a species composition more heterogeneous than expected by chance). Row and column totals (species number and incidence totals) are given. Storage facility, sampling location and species codes are as in table 1.

the irrelevance of model underlying this type of species composition (i.e. smaller assemblages contain successive subsets of the species in larger assemblages) to mite community of storage facilities (WORTHEN, 1996).

A negative, significant correlation was found between the elevation of storage facilities and both mite overall abundance and number of taxa (similar SPEARMAN's $r_S = -0.926, p < 0.05, n = 6$, for the two parameters) (Table 2). The importance of elevation was also proved from results of CA on the species abundance data for the 16 sampling locations (Table 1). CA provided two main axes (Fig. 2) which accounted for a total of 42% of the total variance. The first CA axis appeared as an elevation gradient. It separated indeed the three locations in the silo of Karaj situated at high altitude and characterized by similar assemblage patterns (low species number and strong numerical dominance by the predator *Acaropsellina sollers*) from locations clustered close together near the origin of axis. This cluster contains all the locations at low altitude and with, on the whole, a high number of taxa and another predator, namely *Cheyletus malaccensis*, numerically dominant (in eight assemblages out of 11). The second CA axis showed the same separation. Yet it distinguished also the dust location S_{2d} from all the other locations. In consideration of environmental data at our

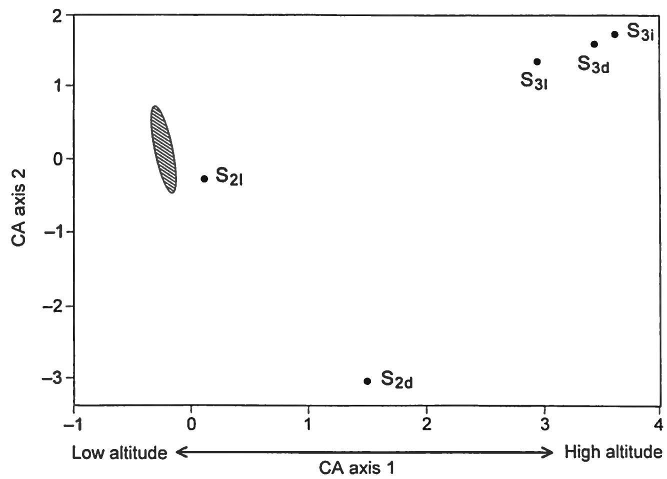

Fig. 2 — Ordination of 16 sampling locations from storage facilities in Iran on the first two axes of the correspondence analysis performed on mite abundance data. Sampling location codes are as in table 1. The locations that cluster together near the origin of the axes (the zone they occupy is encircled and hatched) include nine locations (i.e. S_{1i}, S_{1l}, S_{1d}, F_{1Al}, F_{1Ar}, F_{1Ac}, F_{1Bl}, F_{1Br} and F_{1Bc}) situated at low altitude (40 m) and two locations (i.e. S_{2i} and F_{2l}) situated at intermediate altitude (160 m).

Table 2 — Overall abundance and number of mite species collected from storage facilities in Iran during October 1997. Site elevation and climate data obtained from nearby weather stations are given.

	No. of individuals	No. of taxa	Elevation (m)	Air mean monthly temperature (°C)	No. of months with air mean temperature > 15°C	Difference of temperature between hottest and coldest month (° C)	Air mean monthly R.H.	No. of months with air mean R.H. > 75%
Neka silo (S_1)	1075	14	40	17.0	6	19.9	79.9	12
Gorgan silo (S_2)	554	10	160	17.1 .	7	21.3	70.8	2
Karaj silo (S_3)	228	7	1320	14.9	5	23.5	50.8	0
Memarian flour-mill (F_{1A})	616	12	40	17.0	6	19.9	79.9	12
Rezay flour-mill (F_{1B})	1595	15	40	17.0	6	19.9	79.9	12
Tolou flour-mill (F_2)	277	8	160	17.1	7	21.3	70.8	2

disposal, this contrast as well as others detected in higher order axes (not shown) could not be interpreted with certainty. An elevation gradient was also highlighted in CA performed on the species presence/absence dataset but only for the second axis. This axis which explained 17% of the total variation assessed the divide between locations at both high and intermediate altitudes (except one, namely location F_{2l}) and those at low altitude (not shown). The first axis for its part accounted for 26% of the total variation. It separated the location S_{1l} characterized by a peculiar species composition (i.e. the existence of four taxa out of eight collected exclusively in this place) from all the others.

Specific climatic conditions rather than a proper effect of the altitude determine the mite population growth in higher regions. So, in the place at the highest elevation (i.e. in Karaj) where the minimum and maximum air mean monthly temperatures were respectively 5°C and 2°C lower than in other places, low overall abundance and low species number (Table 2) are likely to result from the more severe climatic conditions. This was confirmed by the observation of a relationship between overall abundance as well as number of taxa and the difference of temperature between the hottest and the coldest month (for both parameters, SPEARMAN's $r_S = -0.926$, $p < 0.05$, $n = 6$) (Table 2). Yet no relationship was detected between the two parameters and both air mean monthly temperature and number of months with air mean temperature higher than 15°C (for both parameters, SPEARMAN's $r_S < 0.001$, $p > 0.999$, $n = 6$). On the other hand, there was a positive relationship between both overall abundance and number of taxa and the two hygrometric variables studied (for all, SPEARMAN's $r_S = 0.926$, $p < 0.05$, $n = 6$) (Table 2). In pursuance of observations by SINHA (1968) and ARMITAGE (1984), the results from community analysis and previous correlations suggest that climatic conditions are major factors in guiding mite community assembly and that biocides are of minor importance.

Discussion

A prominent feature of this survey was the low population density of mites in grain. Such a result has already been reported from stored-grain surveys in Iraq (MAHMOOD, 1992) and in Iran (ARDESHIR *et al.*, 2000). Infestation levels appear to be related to the frequency of fumigant application to the storage facilities (EMMANOUEL *et al.*, 1994). There is a correspondence between the densities in grain and those reported in other temperate regions after surface chemical treatments, i.e. less than 10 mites per kg at the surface of 20 ton bins of wheat in England (ARMITAGE *et al.*, 1994). In this study, overall abundance was indeed lower than 75 mites per 500 g in almost all grain locations in silos, and exceeded scarcely 250 individuals per 500 g in the two sampling locations S_{2i} and F_{2l}. Though formal assessment is required, it is likely that the difference in overall abundance between grain and refuse locations that our results demonstrate is a discernible effect of biocides on populations developing in the grain.

Although cyclic occurrences of prey and predator species has been reported (e.g. HURLOCK *et al.*, 1980), the higher proportion of predatory mites recorded in this study, notably cheyletid species (a similar trend was detected in other seasons; unpublished data), might be attributed to their reduced pesticide susceptibility (ZDARKOVA & HORAK, 1987; WHITE & SINHA, 1990; ZDARKOVA, 1994, 1997).

That surface treatment was unable to control the cheyletids has also been reported by ARMITAGE *et al* (1994). Feeding habits and behaviour of the cheyletids would also explain their survival. By cannibalism as well as by endurance, the cheyletids were shown to survive a long period of food scarcity (SOLOMON, 1969). In addition, polyphagy is common among this group of predators. A number of species belonging to the family, notably *Cheyletus malaccensis* and *Nodele calamondin*, are known to prey upon eggs and young larvae of insects like moths and grain beetles.

The abundance of parasitic pyemotids in the storage facilities studied suggests high infestations with insects. Actually, a total of ten species of Coleoptera belonging to six families were collected in grain and refuse from all the sites (ARDESHIR, 2002).

Low mite population densities may be also explained by the short-term storage in countries (e.g. Iran) where most of the grain imported or locally produced are consumed during the year (FREEMAN, 1973). Here, the very low occurrence of tarsonemid and tydeid species, which are characteristically found in ageing grain (SINHA, 1963), highlighted the low decay rate of the stored grain.

Regarding granivorous mites, it has been shown (PAGLIARINI, 1979; NANGIA & CHANNABASAVANNA, 1989; MAHMOOD, 1992; EMMANOUEL *et al.*, 1994) that the major grain mite species *Acarus siro* is less adapted than *Tyrophagus putrescentiae* and *Lepidoglyphus destructor* to a dry and warm climate, as was first suggested from laboratory investigations (CUNNINGTON, 1976). By contrast, the predator *Cheyletus* appears less sensitive since it can complete its development at lower humidity and higher temperature than the astigmatid mites. It occurs fairly frequently in grain of moisture content (11-12%) too low to support the others (SOLOMON, 1946, 1969).

Under semi-Mediterranean climatic conditions in northern Iran, both *Acarus siro* and the thermophilic species *Aleuroglyphus ovatus* were present, but in low numbers in these storage facilities, probably because of intensive chemical control, though predatory mites may also have contributed to the decline in astigmatid populations. Their low abundance in comparison with other major storage species such as *Lepidoglyphus destructor* and *Tyrophagus putrescentiae* would argue for the lesser adaptation of these typical granivorous species more restricted to indoor environments.

Although *Lepidoglyphus destructor* seems experimentally easier to kill with pesticides than *Acarus siro*

(WILKIN & STABLES, 1985), its persistence and even predominance in treated storage facilities (EMMANOUEL *et al.*, 1994) might be explained by its high capacity for hypopus formation. The facultative deutonymph is known to be specially resistant to many control measures both physical and chemical, and the highly variable hypopus response of *Lepidoglyphus destructor* also enables the species to colonize habitats fluctuating unpredictably, life strategies that ensure survival and dispersal. By contrast, most natural population of *Acarus siro* fail to produce hypopodes (KNÜLLE, 1991, 1995). *Tyrophagus putrescentiae* does not produce hypopodes but its ability to survive and to reproduce on a wide variety of fungi ensures a large distribution in diverse habitats. In numerous ways, *Tyrophagus putrescentiae* and *Lepidoglyphus destructor* show a high adaptive flexibility. The current survey can highlight this feature.

Other mites such as pyroglyphids occasionally found in stored products are still less sensitive to desiccation than the true storage mites, insofar as small populations can survive at relative humidities as low as 33%. Since pyroglyphids are commonly associated with vertebrates, the large numbers of *Dermatophagoides farinae* found in residues in this survey may be attributed to the continual occurrence of nesting birds and rodents within the storage facilities.

In addition to a lowering in abundances, the results from the study indicate an association between mite community organization and site elevation, revealing how important climate-related factors may be. For instance, the dominance of the predatory mite *Acaropsellina sollers* in the silo of Karaj situated at a high altitude suggests a better adaptation to the local climate. Also, an additional survey at altitudes ranging from 200 to 1200 m is required to assess irrevocably this association and to investigate habitat specialization. If current issues are confirmed, a second step of our work on mites in storage facilities will be to investigate the effects of macro-climate as well as micro-climate on community composition (the importance of grain moisture content and temperature on the ecology of storage mites is a well-known fact). Actually, these effects can be deterministic (e.g. direct incidence of climatic conditions on metabolic rates, reproduction and survival) and stochastic (e.g. seasonal shifts in climate generating disturbance). Moreover, even if community responses to climate often appear to be well behaved (review in STEVENS, 1992, and GASTON & CHOWN, 1999), the specific role of amplitude as well as frequency of climatic disturbance, like other disturbances (e.g., in our case, physical disturbance generated by replacement of grain stock), remains an open question (DRAKE, 1990; SAMUELS & DRAKE, 1997; BELYEA & LANCASTER, 1999).

In summary, low abundance is a major characteristic of the mite assemblages inhabiting storage facilities in the Middle East. Biocides are likely to influence species abundance, whereas their role as a causal mechanism for mite community assembly is doubtful. By contrast, the mite community appears to react to climate. The relevance of some climatic factors (e.g. the difference of temperature between the hottest and the coldest month, the air mean monthly R.H., and the number of months with air mean R.H. > 75%) in explaining distribution patterns of species and in shaping species composition of assemblages remains to be assessed.

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