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Distribution and diversity of wheat aphid parasitoids (Hymenoptera: Braconidae: Aphidiinae) in Iran

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Key words. Cereal aphids, parasitoids, Aphidiinae, Braconidae, Iran, biodiversity

Abstract. Eleven species of parasitoids were found to attack 7 species of wheat aphids in Iran. The Simpson's Index of diversity (*D*) used to compare the aphidiine diversity in various cereal crop systems in geographically different regions of Iran ranged from 0.197 to 0.488, depending on locality. There were significant differences among species diversities at different altitudes. The central highlands (1000–1500 meters above mean sea level) were the areas with the most diverse aphid parasitoid complex, differing significantly from that at lower and higher altitudes. We found that altitude explained about 10% of the cereal aphid parasitoid distribution pattern in Iran. Species of the genus *Aphidius* Nees were the most abundant and widely distributed. These were *Aphidius rhopalosiphi* De Stefani, *Aphidius uzbekistanicus* Luzhetski, *Aphidius colemani* Viereck and *Aphidius matricariae* Haliday. *A. uzbekistanicus*, *Ephedrus plagiator* (Nees) and *Ephedrus persicae* Froggat were encountered mainly on the plains at lower altitudes. *Diuraphis noxia* (Kurdjumov) was mainly recorded at higher altitudes in Iran along with its dominant parasitoid species, *Diaeretiella rapae* (MIntosh). The fact that Iran is close to the presumed area of *D. noxia* origin (Central Asian submountains) could be very important in further biological control efforts against this pest aphid. According to our results, *Aphidius ervi* Haliday is a very rare parasitoid of cereal aphids in Iran, which contrast with its high abundance in Europe and North America.

INTRODUCTION

Cereal aphids are serious pests causing damage either directly or by the transmission of viruses (Fiebig & Poehling, 1998), in many areas all over the world. Aphid feeding on plant sap causes significant reduction in grain protein (Ba-Angood & Stewart, 1980). Aphids may also cause damage by injecting toxic salivary secretions during feeding. Direct effects of aphid feeding on cereals include yellowing and premature death of leaves, stunting of the stems and reduction in grain size (van Emden & Harrington, 2007).

Aphid parasitoids are important in the bio-control of aphid pests (Schmidt et al., 2003; Brewer & Elliott, 2004). The taxonomy, distribution and abundance of cereal aphid parasitoids have been well investigated in many parts of the world (Starý, 1976a, b, 1981; Powell, 1982; Pennacchio & Höller, 1990; Höller, 1991; Tomanović et al., 1999, 2005). Furthermore, several attempts have been made worldwide to introduce (Tanigoshi et al., 1995; Halbert et al., 1996) and use the mass release (Levie et al., 2005) of cereal aphid parasitoids, for the purpose of biological control. Although some of the cereal aphids and their parasitoids have been studied in a few areas of Iran (Bandani et al., 1993; Shahrokhi et al., 2004), little is known about the distribution and diversity of aphidiine parasitoids. The majority of field studies, however, deal with only one group of aphid enemies at a time, leaving the regional diversity and host range of this trophic assemblage unexplored. Cereal aphid parasitoids are known to have different host ranges (Kavallieratos et al., 2005), but their complicated host preferences are unknown.

Biological diversity can be quantified in many different ways (Magurran, 1988; Henderson, 2003). Diversity indices provide more information about community composition than simple species richness (Gaston & Spicer, 2004). In this study the Simpson's Index of diversity (*D*) was used to compare the aphidiine diversity in various cereal crop systems in geographically different regions of Iran. Furthermore, the pattern of cereal aphid parasitoid distribution in Iran, constrained by altitude and aphid hosts availability, was explored.

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Localities	Coordinations	Altitude (m AMSL)
1 Abadeh (Aba)	31° 08' N, 52° 40' E	1990
2 Dezful (Dez)	32° 24' N, 48° 23' E	147
3 Golgun (Gol)	32° 59' N, 58° 49' E	1198
4 Gorgan (Gor)	36° 50' N, 54° 29' E	174
5 Hamadan (Ham)	34° 47' N, 48° 30' E	1876
6 Iranshahr (Ira)	27° 15' N, 60° 40' E	551
7 Isfahan (Isf)	32° 39' N, 51° 40' E	1350
8 Kazerun (Kaz)	29° 37' N, 51° 39' E	1610
9 Kharameh (Kha)	29° 30' N, 53° 19' E	1599
10 Mahyar (Mah)	32° 16' N, 51° 48' E	1650
11 Marivan (Mar)	35° 31' N, 46° 10' E	1300
12 Marvdasht (Mav)	27° 37' N, 52° 59' E	1580
13 Mashad (Mas)	36° 17' N, 59° 36' E	1100
14 Meimeh (Mei)	33° 45' N, 51° 17' E	1998
15 Mianrahan (Mia)	34° 37' N, 53° 39' E	1553
16 Noorabad (Noo)	31° 56' N, 50° 30' E	1690
17 Peykanshahr (Pey)	35° 18' N, 51° 37' E	1260
18 Qom (Qom)	34° 40' N, 51° 05' E	928
19 Ramhormoz (Ram)	31° 16' N, 49° 36' E	179
20 Rask (Ras)	26° 14' N, 61° 24' E	378
21 Salafchegan (Sal)	34° 28' N, 50° 27' E	1374
22 Saravan (Sar)	27° 13' N, 61° 41' E	900
23 Saveh (Sav)	35° 20' N, 50° 22' E	950
24 Shahinshahr (Sha)	32° 48' N, 51° 32' E	1585
25 Shiraz (Shi)	29° 36' N, 52° 32' E	1527
26 Songhor (Son)	36° 31' N, 48° 12' E	1732
27 Tehran (Teh)	35° 44' N, 51° 30' E	1240
28 Zabol (Zab)	31° 20' N, 61° 29' E	485
29 Zahedan (Zah)	30° 58' N, 61° 41' E	1352

Fig. 1. The localities where the samples were collected. The numbers on the map are listed to the left of the figure along with the coordinates and altitudes. Each location consists of 5–10 fields. Coordinates are those of a representative location.

MATERIAL AND METHODS

This study was carried out in 12 provinces of Iran. Twenty-nine localities (Fig. 1) were selected so as to include different climatic and geographic conditions, and the different production systems under which winter wheat, *Triticum aestivum* L. is conventionally managed. The wheat was sampled twice at the milky ripe stage of development at all localities (Zadoks et al., 1974). Samples were collected from April till August during 2003–2005 depending on the growing season at each locality. Five to 10 wheat fields per locality were selected and sampled to reduce sampling errors. To reduce field edge effects the samples were collected within each field along a ZigZag line following the lines connecting the corners. On each sampling date and from each field, 50 leaves from 50 milky ripe plants in average were chosen, carefully cut off and transported to the laboratory inside mesh covered semi-transparent plastic boxes. Each leaf bearing colonies of living and mummified aphids was kept in a separate vial. Each vial was numbered and labeled with the date, the field and locality. The vials were inspected daily for the presence of mummies. Once they were detected, they were carefully removed from the leaves and kept individually in small plastic boxes. A circular opening was cut into the lid of each box and covered with muslin for ventilation. Each plastic box was labeled with the number of the vial the mummy was removed from. The mummies in the colonies from which no parasitoids emerged were ignored. The samples were reared in the laboratory at room temperature for 2–3 weeks, until all adult parasitoids emerged. Abundance of parasitoids was assessed by counting both male and female specimens that emerged from each aphid species.

Parasitoid regional diversity was analyzed using Simpson's Index (Krebs, 1998, 2002). Simpson's Index represents the probability of two randomly selected individuals in a habitat belonging to the same species. Large values of the index correspond to low diversity.

Frequency and diversity (*D*) of aphid parasitoids of the common aphid hosts at different altitudes were compared using Kruskal-Wallis *H* non-parametric analysis. If significant differences were detected, multiple pairwise comparisons were made using the Mann-Whitney *U* non-parametric test ($P < 0.05$). Statistical analyses was carried out using the Minitab software (MINITAB, 2000) and SPSS (SPSS, 2004).

The influence of host availability and altitude on the pattern of parasitoid distribution among localities was explored using Canonical Correspondence Analysis (CCA) (Legendre & Legendre, 1998), in which the variability of a data matrix is constrained by a set of external/environmental variables. Then, any pattern in the data matrix can be further accounted for by correlation with possible extrinsic explanatory variables. This analysis was performed on the 9 parasitoids × 29 localities dataset constrained by a 6 (altitude and 5 aphid hosts) × 29 localities external matrix. The data were ln-transformed (ln + 1 for species counts) and the analysis carried out using the PC-ORD software package (McCune & Mefford, 1999). The significance of the observed relationship between the matrices was assessed by a randomization test according to program specifications.

Only aphidiine parasitoids were included in this study as aphelinids were rarely found.

RESULTS

In total, 6351 specimens of aphid parasitoids were collected and identified. Eleven species of parasitoids were found to attack seven species of wheat aphids. The frequency and diversity indices of aphid parasitoids at different sampling localities are presented in Table 1. Some species of parasitoid showed a significant bias toward particular aphid species.

The quantitative assemblage of the parasitoids on different host aphid species is presented in Table 2. *Praon*

TABLE. 1. Frequency of occurrence of aphid parasitoids at different sampling localities in Iran in the whole sample (Simpson's Index of diversity, *D*).

Localities	*D*	*Aphidius colemani*	*Aphidius rhopalosiphi*	*Aphidius uzbekistanicus*	*Aphidius matricariae*	*Aphidius ervi*	*Diaeretiella rapae*	*Ephedrus persicae*	*Ephedrus plagiator*	*Praon volucre*	*Adialytus ambiguus*	*Lysiphlebus fabarum*	SUM
		No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	No.	
Abadeh	0.3889	–	150	–	–	–	119	–	–	46	–	–	315
Dezful	0.2927	–	57	111	28	–	–	–	–	70	–	–	266
Golgun	0.2231	39	29	31	–	–	69	–	–	33	–	–	201
Gorgan	0.4029	19	–		–	15		–	–	43	–	–	77
Hamadan	0.2532	–	17	29	83	–	56	–	–	34	–	–	219
Iranshahr	0.3557	30	–		30	–	14	–	–	–	–	–	74
Isfahan	0.1997	80	48	37	–	–	35	–	–	63	–	9	272
Kazerun	0.3722	223	48	18	–	–	74	–	–	33	–	–	396
Kharameh	0.3532	–	71	–	–	–	78	–	–	41	–	–	190
Mahyar	0.2900	9	38	–	–	–	42	–	–	44	–	–	133
Marivan	0.2856	23	57	–	–	–	22	–	–	40	–	–	142
Marvdasht	0.3790	–	67	–	–	–	39	–	–	16	–	–	122
Mashad	0.3097	–	26	143	–	–	89	–	–	161	–	–	419
Meimeh	0.2605	–	79	96	–	–	42	–	3	72	–	–	292
Mianrahe	0.4507	–	137	–	13	–	52	20	–	49	–	–	271
Noorabad	0.2791	–	14	13		–	24	–	–	33	–	–	84
Peykanshahr	0.2193	87	–	104	89	–	46	–	–	44	–	–	370
Qom	0.1970	6	90	37	58	–	54	10	–	43	–	–	298
Ramhormoz	0.3684	–	38	108		–	–	–	5	66	–	–	217
Rask	0.2518	23	–	34		–	25	–	–	35	–	–	117
Salafchegan	0.1999	–	37	31	29	–	41	–	–	27	–	–	165
Saravan	0.3035	30	41	–		–	61	–	–	16	–	–	148
Saveh	0.2196	–	84	59		11	58	14	–	42	–	–	268
Shahinshahr	0.3122	–	78	27		–	29	–	–	31	–	–	165
Shiraz	0.2579	12	35	32		17	98	–	–	24	4	–	222
Songhor	0.4884	–	19	21		–	–	–	–	–	–	–	40
Tehran	0.2356	–	51	39	14	–	31	–	–	67	–	–	202
Zabol	0.4681	16	49	25		–	39	373	4	–	–	14	520
Zahedan	0.3005	10	40	–		–	38	58	–	–	–	–	146
Total		607	1400	995	344	43	1275	475	12	1173	4	23	6351

volucre (Haliday) was a common and sometime the most frequent species, attacking mostly *Schizaphis graminum* (Rondani) followed by *Sitobion avenae* (Fabricius) (Fig. 2). *Diaeretiella rapae* (M'Intosh) parasitized mainly *Diuraphis noxia* (Kurdjumov), and made up 12.63% of the total association. *Aphidius rhopalosiphi* De Stefani was the most abundant parasitoid of *Metopolophium dirhodum* (Walker) and *Rhopalosiphum padi* (L.), and the second major parasitoid of *S. graminum* (Table 2). The mean frequency of the most common parasitoids of the four common cereal aphid species is shown in Fig. 3. Among the members of each parasitoid complex, a significant difference was detected for *S. avenae* (X^2 = 11.290; *df* = 3; *P* = 0.010). *Aphidius uzbekistanicus* Luzhetzki was the most common parasitoid of *S. avenae* followed by *A. rhopalosiphi* and *P. volucre* (Table 2).

Diversity of the parasitoids of the common aphid species is shown in Fig. 4. The Simpson's Index ranged from 0.197 to 0.488, depending on the locality (Table 1). The most diverse assemblage of parasitoids attacked *S. graminum* followed by *R. padi*, *S. avenae* and *M. dirhodum*. The Simpson's Index of diversity for other aphids was near to 1, which is the lowest value of diversity. In the latter group of cereal aphids, *D. noxia* was attacked frequently by *D. rapae* and very rarely by *P. volucre*. While *D. rapae* was mostly found in association with *D. noxia*, it was also reared from other cereal aphids as well (Fig. 2). *Aphidius* Nees species were the most abundant and widely distributed: *A. rhopalosiphi*, *A. uzbekistanicus*, *Aphidius colemani* Viereck and *Aphidius matricariae* Haliday. In regions manifesting similar complexes, *A. rhopalosiphi* was the main parasitoid of the wheat aphids, followed by *A. uzbekistanicus*, while the rest were of variable importance depending on the region. *Aphidius ervi* Haliday was found in surprisingly low numbers and only in association with *S. avenae* (Table 1, Fig. 2).

Ephedrus plagiator (Nees) as well as *Ephedrus persicae* Froggat emerged occasionally from cereal aphids. The latter was never reared from *S. avenae*. *E. persicae* was the most frequent and dominant parasitoid in the Sistan plain region, comprising 77% of the parasitoid species, attacking mostly *S. graminum* and *R. padi*. In the parasitoid complex of *M. dirhodum*, only *E. persicae* had a low value. The broadly oligophagous parasitoid, *Lysiphlebus fabarum* (Marshall), only occasionally attacked the wheat aphids.

The trend in diversity with increasing altitude is shown in Fig. 5. We tested for differences in diversity among

TABLE 2. Frequency of aphid parasitoids reared from different aphid species.

Parasitoids	Host aphids						
	Schizaphis graminum	*Rhopalosiphum padi*	*Sitobion avenae*	*Metopolophium dirhodum*	*Diuraphis noxia*	*Rhopalosiphum maidis*	*Sipha elegans*
	No.	No.	No.	No.	No.	No.	No.
Aphidius colemani	339	123	145				
Aphidius matricariae	110	58	147	29			
Aphidius rhopalosiphi	362	234	492	312			
Aphidius uzbekistanicus	216	75	618	86			
Aphidius ervi			43				
Diaeretiella rapae	231	49	164	29	802		
Ephedrus persicae	331	124		20			
Ephedrus plagiator	4	3	5				
Praon volucre	585	57	446	39	11	35	
Adialytus ambiguus							4
Lysiphlebus fabarum		23					

localities by comparing four altitudinal locality groups (Fig. 6). There were significant differences among species diversities at different altitudes ($X^2 = 9.081$; $df = 3$; $P = 0.028$). The central highlands (1000–1500 m AMSL) had the most diverse complex ($D = 0.247 \pm 0.016$) of aphid parasitoids, differing significantly from that at lower ($U = 5.00$; $P = 0.028$) and higher ($U = 14.00$; $P = 0.009$) altitudes.

The results of the canonical correspondence analysis are presented in Fig. 7. The structure of the ordination was dominated by *E. persicae* on the first, and *A. ervi* on the second axis. The majority of the parasitoids (*A. colemani, A. matricariae, A. rhopalosiphi, A. uzbekistanicus, D. rapae, P. volucre, L. fabarum*) were, however, positioned near the origin with a low contribution to the ordination, suggesting that the ordination of samples was only weakly due to the differential distribution of parasitoids or the existence of parasitoid assemblages. The imposition of altitude and availability of aphid hosts provided two factors, the first (eigenvalue: 0.088, percent explained variance: 9.5%, correlation with species matrix $r = 0.729$) being the contrast between *D. noxia* at high altitudes and *R. padi* at low altitudes. The second factor (eigenvalue: 0.079, percent explained variance: 8.6%, correlation with species matrix $r = 0.687$) was interpreted as the availability of *R. maidis* as a host for *A. ervi*, specifically for the samples from Gorgan and Hamadan. The remaining aphid hosts (*S. avenae*, *S. graminum* and *M. dirhodum*) did not contribute to these two dimensions. These factors, however, were not statistically significant. Although these correlations seem to be large, a standard randomization test yielded a non-significant P of 0.651 for the eigenvalue and 0.487 for the correlation (subsequent dimensions cannot be significant in that case). Therefore, it can be concluded that these factors have only a weak effect and other factors, not analyzed in this study, have a greater importance in affecting parasitoid distribution.

DISCUSSION

The geographic distribution of parasitoids depends on the plant communities and associated aphids, as well as on their faunal history (Starý, 1968, 1970). Both, altitudinal and latitudinal differences in parasitoid diversity play an important role in the biological control, especially of important pests. Such information is of vital importance in the search for potentially useful biocontrol agents. Völkl (1989) found differences depending on the altitudinal zonation in the composition of the parasitoid complex of *Aphis fabae cirsiiacanthoidis* Scopoli in France. Also, Starý et al. (2004) recorded that the exotic parasitoid species, *Lysiphlebus testaceipes* (Cresson) is able to occupy higher altitudes on the Iberian Penninsula because of its extensive host range in combination with respective changes due to the increasing altitude.

Although we did not find a correlation between diversity and altitude for each parasitoid species some trends were evident. *Ephedrus* species prefer lowland areas (Fig. 7), but *A. rhopalosiphi* and *D. rapae* clearly prefer to parasitize cereal aphids at higher altitudes (Table 1).

While the abundance of aphid parasitoids was primarily a function of host aphid abundance there were significant differences in the species richness and composition as well as in the structure of the parasitoid complexes of the seven cereal aphid species. The factors that affect the structure and composition of these parasitoid complexes most probably are altitude, geographical area, year of

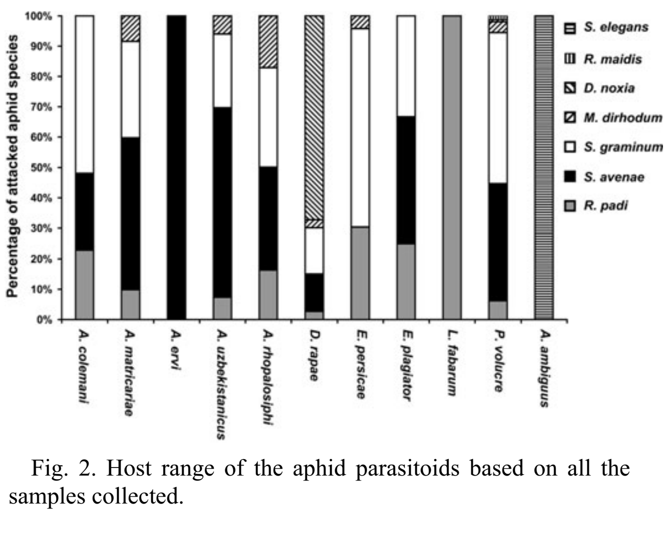

Fig. 2. Host range of the aphid parasitoids based on all the samples collected.

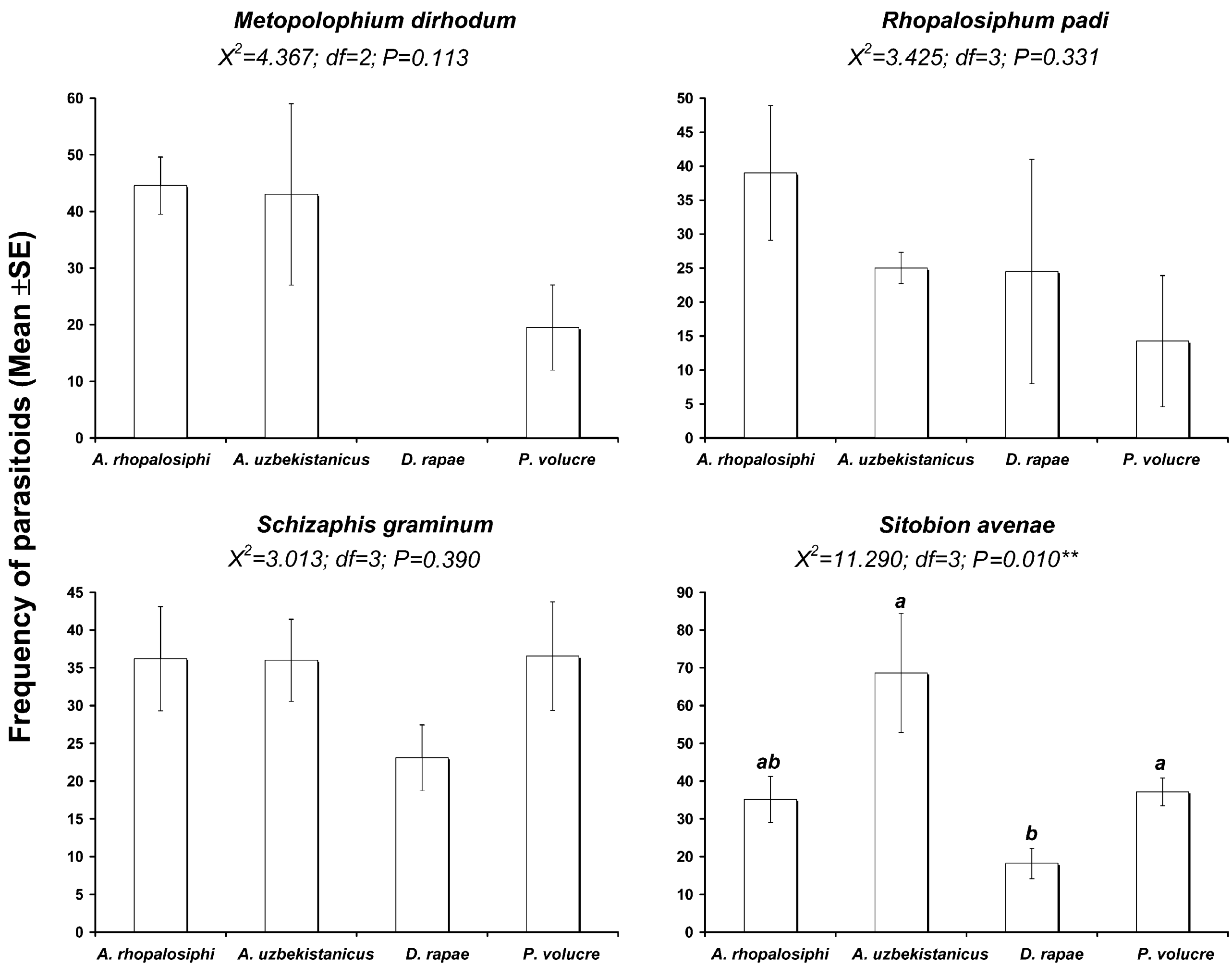

Fig. 3. Frequency of the most common parasitoids parasitizing four species of cereal aphids. Comparisons were made using Kruskal-Wallis *H* non-parametric analysis. A significant difference was found for the parasitoid complex of *Sitobion avenae*, based on all the data.

sampling, agrotechnical measures (wheat variety, mode of cropping, chemical treatments), size of fields and the interactions with neighbouring crops and non-crops. Among the members of the genus *Aphidius*, *A. rhopalosiphi* (*n* = 1400) and *A. uzbekistanicus* (*n* = 995) were the most common species, however, other con-genera having a broad host range (Starý, 1976b; Rabasse & Dedryver, 1983; Rakhshani et al., 2005, 2006), were found occasionally in cereal fields, where the dominant species were absent or uncommon (Table 1). *P. volucre* was also a common member of the cereal aphid parasitoid guild. These common species of parasitoids are the most polyphagous and best adapted to cereal agroecosystems. The differences in the species composition at the different localities can be attributed to the different thermal requirements (Li & Mills, 2004) of the parasitoid species. Temperature, which depends on altitudes, plays an important role in insect population dynamics and densities (Bernal & González, 1997; Leather et al., 1993). Although all aphid species occurred in close proximity to the same host plant species, there was a remarkable overlap in the species assemblage of the parasitoids. The dominance of an aphid species reflected the frequency of the respective parasitoids, especially in the case of *D. noxia*-*D. rapae*.

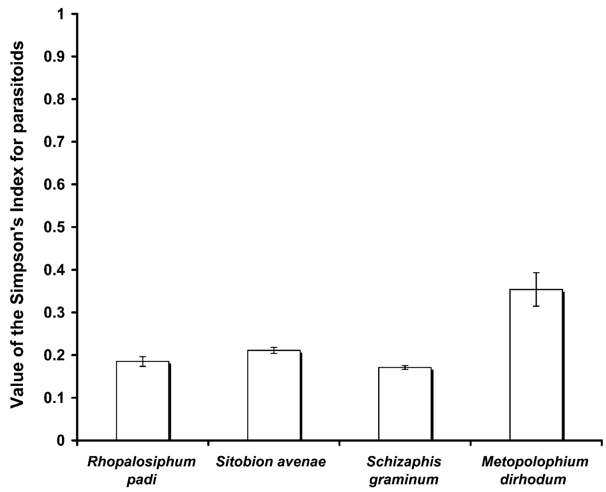

Fig. 4. Simpson's indices of diversity of parasitoids associated with each cereal aphid for all the samples collected.

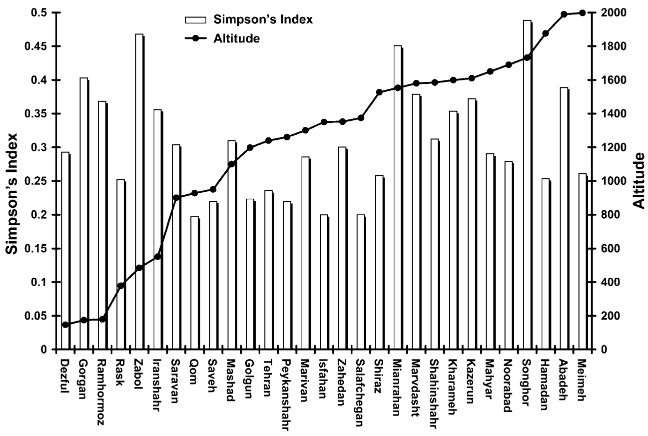

Fig. 5. Fluctuation in the Simpson's Index relative to altitude.

The parasitoid complex of *D. noxia* was surprisingly narrow, compared with the previous records (McKinnon et al. 1992, Bosque-Pérez et al., 2002; Kavallieratos et al., 2004), of the specific host ranges of other parasitoids in this area of Iran. Further confirmatory studies are required. *D. noxia* occurred mainly at high altitudes in Iran along with its dominant parasitoid species, *D. rapae*. The fact that Iran is close to the presumed area of origin of *D. noxia* (Central Asian submountains) could be important for future biological control efforts against this pest aphid (Brewer & Elliott, 2004).

According to our results, *A. ervi* is a rare parasitoid of cereal aphids in Iran, contrary to its high abundance in Europe and North America (Starý, 1976b; Powell, 1982; Pike et al., 1997; Al-Dobai et al., 1999; Sigsgaard, 2002). *S. graminum*, which is the most widely distributed, was parasitized by the greatest diversity of parasitoids. Abundance and host alternation, which are associated with the distribution of aphid species, often affect parasitoid species richness positively, which suggests that aphids with a wide distribution might be exposed to different parasitoid complexes (Starý, 1968, 1970, Stadler, 2002).

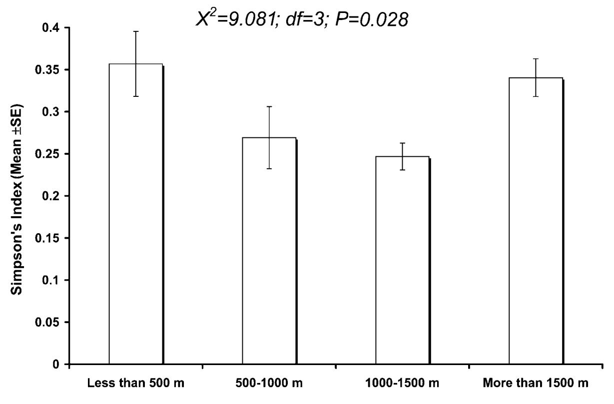

Fig. 6. Fluctuation in the Simpson's Index relative to altitude [in meters (m) above mean sea level (AMSL)], with each locality grouped in one of four altitude ranges.

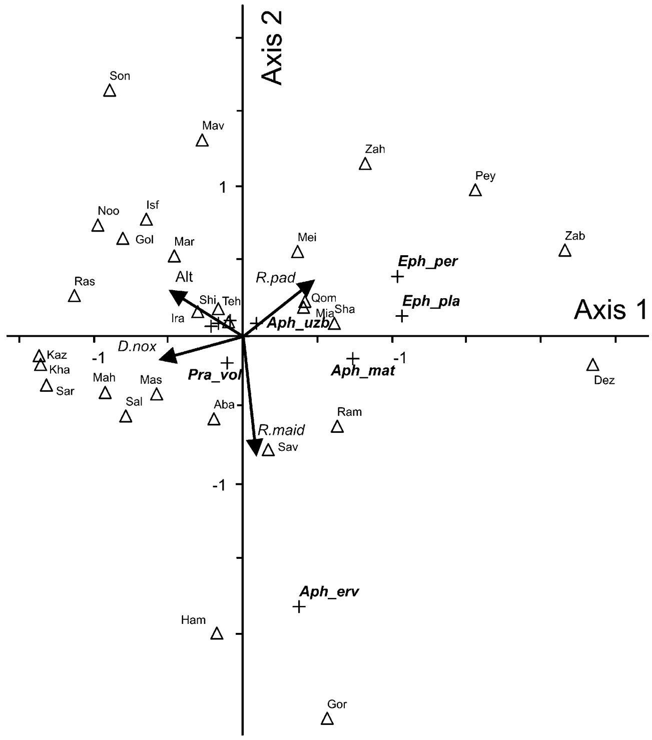

Fig. 7. Plot of the canonical correspondence analysis results of the parasitoid/locality ordination constrained by altitude (Alt) and aphid host (*D.nox – Diuraphis noxia, R.maid – Rhopalosiphum maidis, R.pad – Rhopalosiphum padi*) availability (abbreviations for localities are given in Fig. 1; *Aph_erv – Aphidius ervi*, *Aph_mat – Aphidius matricariae*, *Aph_uzb – Aphidius uzbekistanicus*, *Eph_per – Ephedrus persicae*, *Eph_pla – Ephedrus plagiator*, *Pra_vol – Praon volucre*, the unlabelled parasitoids are, in order from left to right: *Diaeretiella rapae, Aphidius colemani, Aphidius rhopalosiphi*; only external variables with $r^2 > 0.200$ are plotted).

L. fabarum, an occasional member of the cereal parasitoid guild and member of a species-complex, is attacking a wide range of aphids (Rakhshani et al., 2005, 2006), normally not including cereal aphids.

A. colemani with a wide host range (Starý, 1975, 2002; Talebi et al., 2006) did not attack *D. noxia* in the study area, contrary to what is observed in the Near East (McKinnon et al., 1992) and subsaharan Africa (Starý & Erdelen, 1982).

Other species of cereal aphid parasitoids, like *Aphidius avenae* Haliday, *Praon gallicum* Starý, *Trioxys auctus* (Haliday) and *Toxares deltiger* Haliday were not found during this study.

It is concluded that the untreated cereal fields in the highlands (more than 500 m AMSL) are microhabitats for a diverse fauna of specific aphid parasitoids, but not of a taxonomically uniform assemblage. This means that the influence of host species and habitat preference, as defined by altitude, are not the primary factors determining parasitoid diversification in the cereal fields studied. The high diversity and abundance of parasitoids in these regions during spring and early summer can be an important factor affecting the abundance of aphids. The efficacy of the native parasitoids in the field needs to be determined prior to the use of biological control to reduce cereal aphid abundance in Iran.

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