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Citrus-orchard ground harbours a diverse, well-established and abundant ground-dwelling spider fauna

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Abstract

Ground-dwelling spider assemblages comprise one of the most representative predatory groups to be found in many crops. There is some evidence of the role that ground-dwelling spiders play in controlling certain citrus pests; however, there are almost no studies about the abundance and composition of this predatory group in citrus orchards. A three-year survey conducted using pitfall traps in three citrus orchards in Eastern Spain yielded more than five-thousand ground-dwelling spiders belonging to more than 50 species and 20 families. Wandering families such as *Lycosidae*, *Gnaphosidae* and *Zodariidae* were the most numerous in terms of captures. The generalist predator *Pardosa cribata* Simon (Araneae: Lycosidae) was the most common species, representing a quarter of all captures, followed by *Zodarion cesari* Pekar. (Araneae: Zodariidae) and *Trachyzelotes fuscipes* (Koch) (Araneae: Gnaphosidae). Spiders were active throughout the year with a peak population in summer. The species abundance data for the three spider assemblages sampled fitted a log normal statistical model which is consistent with a well-established community. The presence of a cover crop provided higher abundance of alternative prey and consequently higher abundance and diversity of ground-dwelling spiders. This work demonstrates that the citrus-orchard ground harbours a diverse and abundant ground-dwelling spider fauna, which is also active throughout the year. A challenge for future studies will be to establish conservation management strategies for these predators, that will improve biological control of those citrus pests that inhabit or spend part of their life cycle on the orchard floor.

Additional key words: conservation strategies; cover crops; generalist predators; prey; species richness spider assemblage.

Resumen

El suelo del cultivo de los cítricos alberga una fauna de arañas diversa, abundante y bien establecida

Las arañas que habitan en el suelo constituyen uno de los grupos de depredadores más representativos que se encuentran en numerosos cultivos. En cítricos existen evidencias sobre el papel que pueden desempeñar algunas de estas arañas en el control de ciertas plagas. Sin embargo, en este cultivo la información disponible actualmente sobre la abundancia y composición de este grupo de depredadores es muy escasa. Por ello, se llevó a cabo un estudio de tres años mediante trampas de gravedad en campos comerciales de cítricos localizados al este de la Península Ibérica. En este, se obtuvieron más de cinco mil individuos pertenecientes a más de 50 especies y 20 familias. Lycosidae, Gnaphosidae y Zodariidae fueron las familias más abundantes en número de capturas. La especie generalista *Pardosa cribata* Simon (Araneae: Lycosidae) fue la especie más común, seguida por *Zodarion cesari* Pekar (Araneae: Zodariidae) y *Trachyzelotes fuscipes* (Koch) (Araneae: Gnaphosidae). Las arañas se mostraron activas durante todo el año con una población máxima en verano. La abundancia de especies para las tres localizaciones se ajustó a un modelo log normal lo cual indica que se trata de comunidades bien establecidas. Este trabajo demuestra que el suelo de cítricos alberga una abundante y diversa fauna de arañas que además se encuentra activa durante todo el año. Un reto para el futuro será establecer estrategias de gestión para la conservación de estos depredadores, y así mejorar el control biológico de aquellas plagas de los cítricos que habitan o pasan parte de su ciclo de vida en el suelo de los cítricos.

Palabras clave adicionales: cubiertas vegetales; depredadores generalistas; estrategias de conservación; grupos de arañas; presa; riqueza de especies.

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Introduction

Biological control has a long-standing tradition in citrus orchards, where many potential pests are kept under excellent or satisfactory natural control by either exotic or indigenous natural enemies (Jacas and Urbaneja, 2010). Most of these examples refer to specific natural enemies that inhabit the canopy of this crop. Nevertheless, citrus orchards afford the potential to maintain semi-permanent ground habitats that can host a rich complex of arthropods, including saprophagous, phytophagous and natural enemies (Monzó *et al.*, 2005; Vanaclocha *et al.*, 2005; Urbaneja *et al.*, 2006; Aguilar-Fenollosa *et al.*, 2009). Despite this, there are few studies on this fauna, and especially on the ground-dwelling generalist predators, which could play a role in the control of certain citrus pests such as the medfly, aphids or red spider mites that share both, ground and canopy habitats.

Among the natural enemies to be found on the citrus-orchard ground, spider assemblages comprise one of the most representative ground-dwelling predatory groups. Spiders are one of the most diverse groups existing on the planet. Hitherto, around 41,000 species have been described world-wide (Platnick, 2011) and this number is estimated to increase to 60,000-170,000 species (Coddington and Levi, 1991). They can be found in relatively high abundance in agroecosytems (Mansour *et al.*, 1980; Oraze and Grigarick, 1989). Moreover, all known spider species display predatory behaviour and are dominant insectivores in some agro-ecosystems (Thompson, 1984).

Probably due to their generalist predatory behaviour and because spiders do not display a prey-dependent seasonal activity (Symondson, 2002b), there are few examples in agricultural pest control in which a single spider species can control a pest (Sunderland, 1999). Although the action of a single species may not achieve complete control, it can help to reduce populations of certain pests that require a multi-tactic control strategy. One such case is the Mediterranean fruit fly, *Ceratitis capitata* (Wiedemann) (Diptera: Tephritidae), which has been demonstrated to be susceptible to predation by this group of predators (Urbaneja *et al.*, 2006; Monzó *et al.*, 2009, 2010).

Spiders can contribute to significant reductions in pest numbers when present as an assemblage (Sunderland *et al.*, 1997; Sunderland, 1999) due to their great diversity in predatory habits (Bogya and Mols, 1996), foraging strategies (Marc and Canard, 1997), prey preferences (Nyffeler *et al.*, 1990) and spatial and temporal distribution (Nyffeler *et al.*, 1994). Moreover, it is broadly recognized that the diversity of a spider assemblage will confer resilience to sudden environmental changes, facilitating a return to the original equilibrium of population densities (Duelli *et al.*, 1999).

Abundance, seasonal activity and species richness are three important traits of predatory assemblages when applied to biological control. There are numerous studies in agriculture that relate spider abundance with pest mortality, suggesting high predator densities are required for satisfactory phytophagous control (Mansour *et al.*, 1980; Oraze and Grigarick, 1989; Schmidth *et al.*, 2005). In many cases, the early presence of spiders in the crop can reduce pest populations to such an extent that outbreaks are prevented (Riechert and Lockley, 1984) or can facilitate pest control by later-arriving specialist predators (Sunderland, 1999). A high diversity of spider species or genotypes will give rise to a more complex composite of foraging activities, and thus a better chance of a species, or complex of species able to act against a certain pest (Riechert and Lockley, 1984).

A better knowledge of citrus-orchard ground-dwelling spider assemblages could help to identify ecological requirements necessary to improve conservation strategies in the crop, and improve biological control of pest species. Here we report on seasonal activity, relative species and families abundance, and the assemblage-structure population as monitored by pitfall traps in three citrus orchards, with different cover crop management and consequently, with different alternative preys abundances, over a three-year period in the main Mediterranean citrus region (Eastern Spain).

Material and methods

Study sites

Spider populations were surveyed in three 1 ha citrus orchards located in Bétera (UTM X722106 Y4388610; Z30 m altitude), Olocau (UTM X706741 Y4400206; Z 330 m altitude) and Náquera (UTM X722427

Abbreviations used: ACE (abundance-base coverage estimator), ICE (incidence-base coverage estimator), Jack1 (first-order Jackknife estimator), Jack2 (second-order Jackknife estimator), S* (parametric species richness estimator).

Y4385216; Z110 m altitude) (Province of Valencia, Eastern Spain). The first two orchards were maintained with a permanent cover crop whereas the third was bare-soil. All the orchards were drip-irrigated and surrounded by other citrus orchards. In Náquera, glyphosate herbicide was applied in the spring, summer and fall for weed control. In Bétera, a spontaneous natural cover crop was preserved. The most abundant species in this cover crop were the broad-leaved weeds *Convolvulus arvensis* L., *Conyza canadiensis* L. and *Amaranthus retoflexus* L., and the grasses *Hordeum leporinum* Link, and *Avena* sp. accounting for 72% of the ground coverage (B. Belliure, IVIA unpublished results). This cover crop was mowed at the end of spring and the beginning of fall. In Olocau, a monoespecific ground cover of *Festuca arundinacea* Schreber (Poaceae) was maintained.

Sampling of spiders and potential alternative preys

Twelve pitfall traps were regularly distributed diagonally across each orchard to monitor ground-dwelling spider abundance-activity. Each trap consisted of a plastic cup (12.5 cm diameter and 12 cm depth), with a plastic funnel fitted to the top. An inner plastic 150 mL container half filled with a 3:1 mixture of water and ethanol, and 0.1% detergent, was placed inside the plastic cup. Samples were taken from April 2004 until April 2007 in Náquera and Olocau orchards and from August 2003 until August 2006 in the Bétera orchard. Traps were changed every 15 days and the adult specimens of spiders collected were taxonomically identified to at least the family level and in most cases to the species level. First identifications of all the species were conducted by A. Melic. Specimens collected of other macroarthropod orders that could be used as prey by spiders (Nyffeler, 1999) were also counted.

Data analysis

Activity-density patterns

Mean number of adult spider specimens captured per trap and day was calculated for each sampling date and each sampling site. Values were expressed as mean ± standard error. Cumulative number of spiders per trap were analysed using a linear mixed model with repeated measures to estimate variability among seasons and years. Season and year were considered as fixed factors. Main factors and their interactions were included in the model, with the trap as a random factor. Effects with variances that were not significant were removed from the analysis. LSD applying the Bonferroni significant correction was used to compare means among seasons.

Indicators of community structure

The structure of the spider assemblage from each site was studied by fitting species abundance data to log normal, Fisher's logarithmic or geometric series distributions (Magurran, 2004). Log normal distributions describe established and well-structured assemblages resulting from a high number of factors acting in the ecosystem (Magurran, 2004). However, not all the rare species may be registered because the data to which the curve would be fitted are derived from sampling so that the left-hand portion of the curve would be lost. For this reason, the data were fitted to a truncate log-normal distribution (Preston, 1948). Logarithmic and geometric series distributions are most applicable in situations where one or a few factors dominate the ecology of an assemblage. These distributions typically resemble a log-normal when permanent species dominate the assemblage abundance, whereas abundance follows a logarithmic series distribution when occasional species dominate the assemblage (Magurran and Henderson, 2003). In general, the geometric series pattern of species abundance is found primarily in species-poor and disturbed environments, or in the early stages of a succession (Whittaker, 1965, 1972).

The Kolmogorov-Smirnov statistical test, which can be applied to small samples without losing effectiveness (Sokal and Rohlf, 1995), was used to evaluate fit of the data to log-normal, logarithmic and geometric series distributions. Abundance distributions were plotted for each spider assemblage using Preston's method of log 3 bases, in which abundance classes (octaves) had boundaries 1, 3, 9, 27, 81, etc.

Species richnes

True species richness of the three assemblages sampled was estimated by fitting a log-normal abundance distribution and estimating the hidden or unsampled portion of the curve (S* estimator) (Preston, 1948), and also applying the following non-parametric estimators that use the relative abundance of rare species to estimate the number of unseen species: the estimators Chao1 and Chao2 (Colwell and Coddington, 1994; Lee and Chao, 1994), the abundance-base coverage estimator (ACE), the incidence-base coverage estimator (ICE) (Chao *et al.*, 1993), and the Jackknife estimators First-Order Jackknife (Jack1) and Second-Order Jackknife (Jack2) (Heltshe and Forrester, 1983, Smith and van Belle, 1984). The mean value of each non-parametric estimator was plotted against sample number after 50 random re-orderings of samples. If an estimator reaches a plateau before all samples have been added, the value obtained can be considered an adequate estimate of species richness. Conversely, if the estimators are still rising with sampling size, the estimate may still be subjected to undersampling bias (Colwell and Coddington, 1994; Logino *et al.*, 2002). To calculate non-parametric estimators and to investigate the stability of these with sampling addition, the Estimates 8.0 free package software was used (Colwell, 2001).

Results

Species composition and relative abundance

A total of 5,116 adult spider specimens belonging to 51 species and 20 families were captured in 36 pitfall traps during the three-year study, in the three citrus orchards sampled (Table 1). Gnaphosidae, Linyphiidae and Salticidae were the most diverse families in number of species (8 species collected per family). On the other hand, most captures came from the families Lycosidae (1,971), Gnaphosidae (1,353) and Zodariidae (980). The lycosid *Pardosa cribata* Simon was the most frequently captured species with 1,151 individuals collected, representing 22.5% of all captures. This species appeared in high numbers at all the sampling sites. The second most frequently captured species was *Zodarion cesari* Pekar with 947 captures, of which 96.8% came from a single sampling site (Bétera).

Activity-density patterns

Spiders were present throughout the year in all three orchards sampled, although significant differences were found among seasons ($p < 0.0001$ for the three locations) (Fig. 1). In general, higher captures were obtained in summer with secondary peaks in spring and autumn depending on each orchard (Fig. 1, Table 2).

No differences among years were observed for the three orchards separately (Bétera, $p = 0.5288$; Olocau, $p = 0.0730$ and Náquera, $p = 0.0916$) although interactions between season and year were significant (Bétera, $p < 0.0001$; Olocau, $p = 0.0003$ and Náquera,

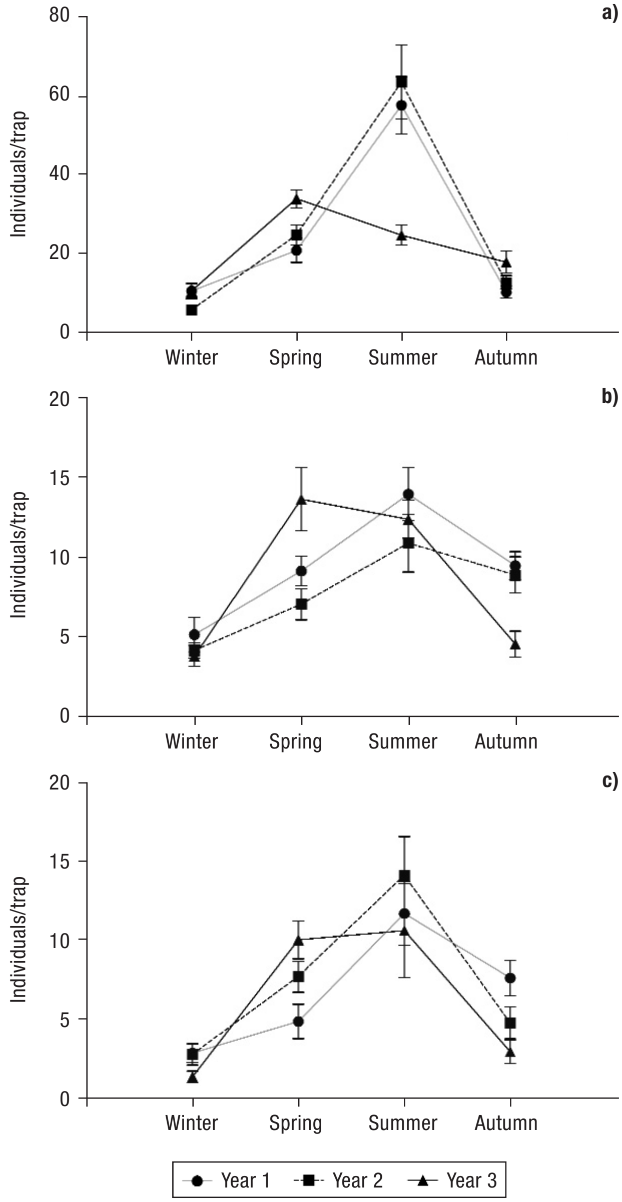

Figure 1. Mean number of spiders (individuals/trap ± SE) collected in pitfall traps during a three-year period in three citrus orchards: (a) Bétera, (b) Olocau and (c) Náquera.

Table 1. Total number of ground-dwelling spiders collected in pitfall traps in three citrus orchards in Valencia, Spain

Species	Family	Bétera	Olocau	Náquera	Total
Pardosa cribata Simon, 1878	Lycosidae	786	111	254	1,151
Zodarion cesari Pekar, 2010	Zodariidae	917	16	14	947
Trachyzelotes fuscipes (L. Koch, 1836)	Gnaphosidae	200	272	86	558
Arctosa perita (Latreille, 1799)	Lycosidae	165	77	53	295
Setaphis carmeli (O.P. Cambridge, 1872)	Gnaphosidae	143	71	58	272
Dysdera crocota C.L. Koch, 1838	Dysderidae	87	45	120	252
Erigone dentipalpis (Wider, 1834)	Linyphiidae	112	53	50	215
Alopecosa albofasciata (Brullé, 1832)	Lycosidae	72	32	60	164
Meioneta fuscipalpis (C.L. Koch, 1836)	Linyphiidae	78	58	24	160
Xysticus bliteus (Simon, 1875)	Thomisidae	110	10	7	127
Hogna radiata (Latreille, 1817)	Lycosidae	64	33	8	105
Haplodrassus dalmatensis (L. Koch, 1866)	Gnaphosidae	34	50	16	100
Nemesia dubia O.P. Cambridge, 1874	Nemesiidae	27	33	18	78
Typhochrestus digitatus (O.P. Cambridge, 1872)	Linyphiidae	61	7	6	74
Tenuiphantes zimmermanni (Bertkau, 1890)	Linyphiidae	15	50	7	72
Titanoeca tristis L.Koch, 1872	Titanoecidae	28	21	11	60
Textris coarctata (Dufour, 1831)	Agelenidae	13	28	16	57
Micaria dives (Lucas, 1846)	Gnaphosidae	5	31	17	53
Pelecopsis inedita (O.P. Cambridge, 1875)	Linyphiidae	36	5	8	49
Phrurolithus minimus C.L. Koch, 1839	Liocranidae	21	11	2	34
Aelurillus aeruginosus (Simon, 1871)	Salticidae	13	5	15	33
Phlegra bresnieri (Lucas, 1846)	Salticidae	21	3	5	29
Xysticus nubilus Simon, 1875	Thomisidae	17	5	4	26
Tegenaria fuesslini (Pavesi, 1873)	Agelenidae	3	21	2	26
Thanatus vulgaris Simon, 1870	Philodromidae	18	3	3	24
Zelotes tenuis (L. Koch, 1866)	Gnaphosidae	6	6	7	19
Textris caudata L. Koch, 1872	Agelenidae	0	19	0	19
Icius hamatus (C.L. Koch, 1846)	Salticidae	9	2	5	16
Oecobius maculatus Simon, 1870	Oecobiidae	8	2	2	12
Cyrtauchenius walckenaeri (Lucas, 1846)	Cyrtaucheniidae	5	7	0	12
Titanoeca hispanica Wunderlich, 1994	Titanoecidae	4	3	2	9
Enoplognatha oelandica (Thorell, 1875)	Theridiidae	0	3	5	8
Haplodrassus severus (L. Koch, 1839)	Gnaphosidae	0	5	1	6
Eresus niger (Petagna, 1787)	Eresidae	1	2	2	5
Pisaura mirabilis (Clerck, 1757)	Pisauridae	1	3	1	5
Zodarion styliferum (Simon, 1870)	Zodariidae	0	0	5	5
Nomisia exornata (C.L. Koch, 1839)	Gnaphosidae	3	1	0	4
Alopecosa sp.	Lycosidae	2	2	0	4
Loxoceles rufescens (Dufour, 1820)	Sicariidae	2	0	2	4
Micaria coarctata (Lucas, 1846)	Gnaphosidae	3	0	1	4
Pelecopsis bucephala (O.P. Cambridge, 1875)	Linyphiidae	4	0	0	4
Steatoda albomaculata (De Geer, 1778)	Theridiidae	0	4	0	4
Thyene imperialis (Rossi, 1846)	Salticidae	2	1	0	3
Erigone vagans Audouin, 1826	Linyphiidae	2	1	0	3
Talavera aequipes (O.P. Cambridge, 1871)	Salticidae	1	0	1	2
Chalcocirtus infimus (Simon, 1868)	Salticidae	1	1	0	2
Cheiracanthium mildei L. Koch, 1874	Miturgidae	0	1	0	1
Linyphiidae sp.	Linyphiidae	1	0	0	1
Olios argelasius (Walckenaer, 1805)	Sparassidae	0	1	0	1
Pseudeuophrys lanigera (Simon, 1871)	Salticidae	1	0	0	1
Zodarion maculatum (Simon, 1870)	Zodariidae	0	0	1	1
Total abundance (N)		3,102	1,115	899	5,116
Total number of species (S)		43	43	38	51

Table 2. Pair-wise comparison (*p*-values) of number of spiders collected per trap between seasons (T1: winter; T2: spring; T3: summer; T4: autumn; linear mixed model with repeated measures). Values in bold correspond to statistically significant differences

Location	Year	T1 *vs* T2	T1 *vs* T3	T1 *vs* T4	T2 *vs* T3	T2 *vs* T4	T3 *vs* T4
Bétera	1	**0.0007**	**< 0.0001**	1.0000	**< 0.0001**	**0.0006**	**< 0.0001**
	2	**< 0.0001**	**< 0.0001**	**0.0007**	**< 0.0001**	**0.0008**	**< 0.0001**
	3	**< 0.0001**	**< 0.0001**	**0.0298**	0.2707	**0.0016**	0.2683
Olocau	1	**0.0218**	**< 0.0001**	**0.0119**	0.0767	1.0000	0.1289
	2	0.1119	**0.0002**	**0.0048**	0.1829	1.0000	1.0000
	3	**< 0.0001**	**< 0.0001**	1.0000	1.0000	**< 0.0001**	**< 0.0001**
Náquera	1	0.4398	**< 0.0001**	**0.0056**	**0.0074**	0.4920	0.4548
	2	**0.0025**	**< 0.0001**	0.3759	0.0872	0.3175	**0.0005**
	3	**< 0.0001**	**< 0.0001**	0.3568	1.0000	**0.0033**	**0.0019**

$p = 0.0011$). These interactions may have been due to the different spider population trends seen the third year (higher spider captures in spring and lower in summer) compared to the previous two years which were similar (Fig. 1).

Indicators of spider community structure

All the sampled spider assemblages fit both the log normal series distribution and the Fisher's logarithmic series model, but none fit the geometric series model (Table 3). The three abundance distributions revealed a mode, especially clear in the Bétera and Náquera orchards (Fig. 2).

Species richness

The non-parametric estimators Chao1 and Chao2, the incidence-base coverage estimator (ICE) the abundance-base coverage estimator (ACE), and the Jackknife estimators First-Order Jackknife (Jack1) and Second-Order Jackknife (Jack2) produced stable estimates of species richness, which hardly increased with the addition of new samples (Fig. 3). All these non-parametric estimators in addition to the S* estimator obtained from the log-normal series distribution, generated estimates that were broadly similar and also not markedly larger than the observed species richness (Table 4). Bétera and Olocau orchards produced the richest estimates of species for all the estimators used (between 47.1-50.91 expected species for Bétera orchard, and 45.1-49.0 for Olocau orchard). On the other hand, the Náquera orchard produced a poorer estimate of species richness (between 39.2-42.9 expected species) although it had the most completely sampled assemblage according to the number of species observed and the number of species estimated. In contrast, Bétera, proved to be the most incompletely sampled assemblage despite being the sampling site where most individuals were captured.

Table 3. Kolmogorov-Smirnov test statistics (D) for the fit of the four assemblage species abundance data to the three theoretical species abundance models: log-normal, logarithmic and geometric series

	Log normal		Log series		Geometric series	
	$D_{0.05}$	D	$D_{0.05}$	D	$D_{0.05}$	D
Bétera	0.136	0.046	0.136	0.038	0.136	0.2989*
Olocau	0.136	0.119	0.136	0.097	0.136	0.1377*
Náquera	0.145	0.043	0.145	0.118	0.145	0.1934*

Critical values have been calculated at the significance level of 0.05. Values of D observed below the critical values ($D_{0.05}$) mean that both the observed and the theoretical distribution are similar. Values of D above the critical values (marked with *) mean that the observed distribution differs from the theoretical distribution.

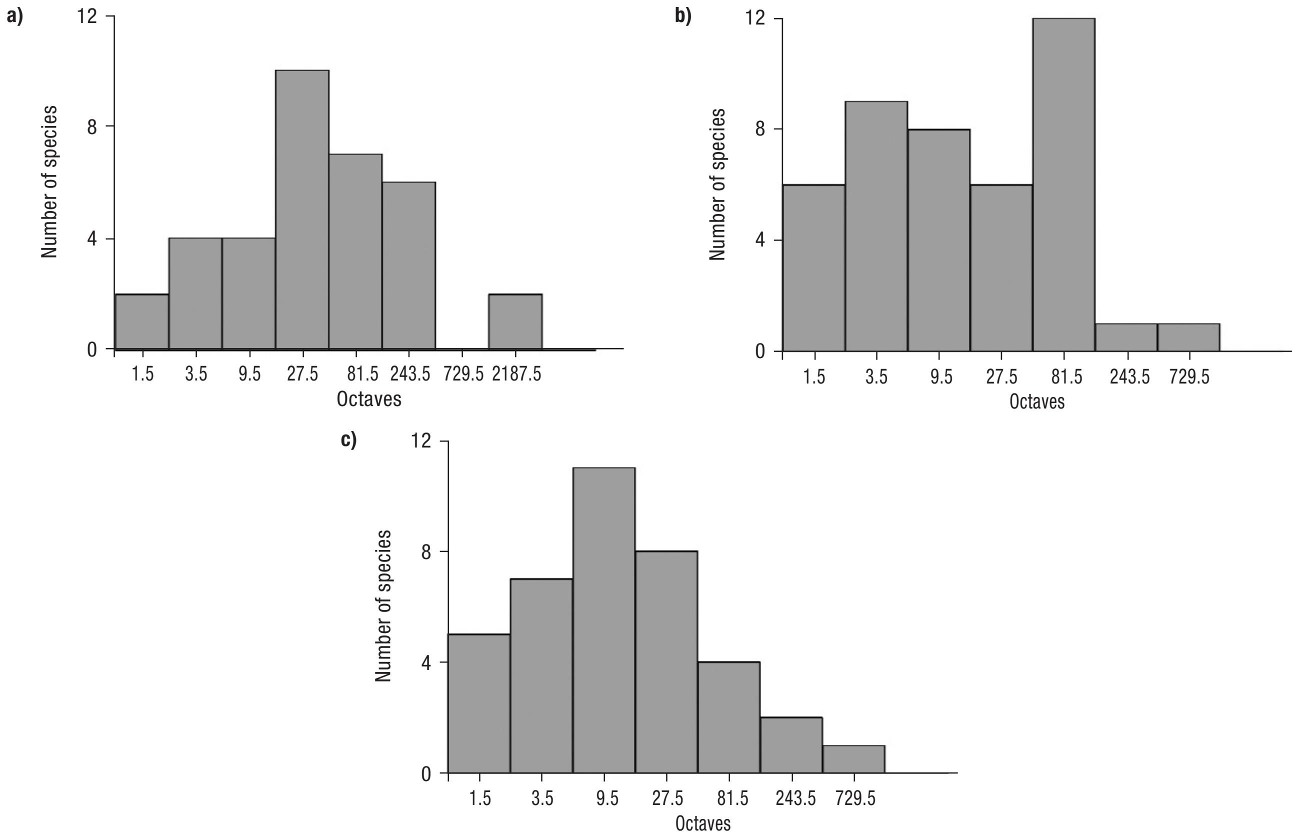

Figure 2. Abundance distributions of ground-dwelling spiders showing number of species in successive abundance classes (octaves) in three citrus orchards: (a) Bétera, (b) Olocau and (c) Náquera.

Potential alternative prey

Isopoda, with 74,683 individuals captured was the most abundant arthropod order followed by Diptera (34,584), Coleoptera (21,358), Hemiptera (9,026), Hymenoptera (2651), Lepidoptera (1,206) and Orthoptera (772). Bétera and Olocau, the orchards maintaining cover crops, registered the highest number of captures for all the arthropod orders studied (Table 5). The number of Coleoptera and Hemiptera captures was

Table 4. Richness estimates for the three citrus orchards sampled. Each richness estimate represents the mean (bold values) for 50 randomizations of sample order [for some estimators, the standard deviation (SD) or the 95% confident limits (CL) are also displayed]. Estimates have been calculated for the parametric estimator S* and the following non-parametric estimators: Chao1 and Chao2, the abundance-base coverage estimator (ACE), the incidence-base coverage estimator (ICE), and the Jackknife estimators First-Order Jackknife (Jack1) and Second-Order Jackknife (Jack2)

	Bétera			Olocau			Náquera		
	Value ± SD	**CL lower**	**CL upper**	**Value ± SD**	**CL lower**	**CL upper**	**Value ± SD**	**CL lower**	**CL upper**
Obs. richness	**43**			**43**			**38**		
ACE	**47.4**			**46.6**			**40.6**		
ICE	**49.1**			**47.3**			**40.6**		
Chao1	**47.5**	43.8	67.9	**46.0**	43.5	61.0	**39.4**	38.2	48.6
Chao2	**47.1**	43.8	63.7	**45.1**	43.3	56.1	**39.2**	38.2	47.3
Jack1	**49.8 ± 3.1**			**48.8 ± 2.2**			**42.9 ± 2.1**		
Jack2	**50.9**			**49.0**			**41.2**		
S*	**47.5**			**45.6**			**40.4**		

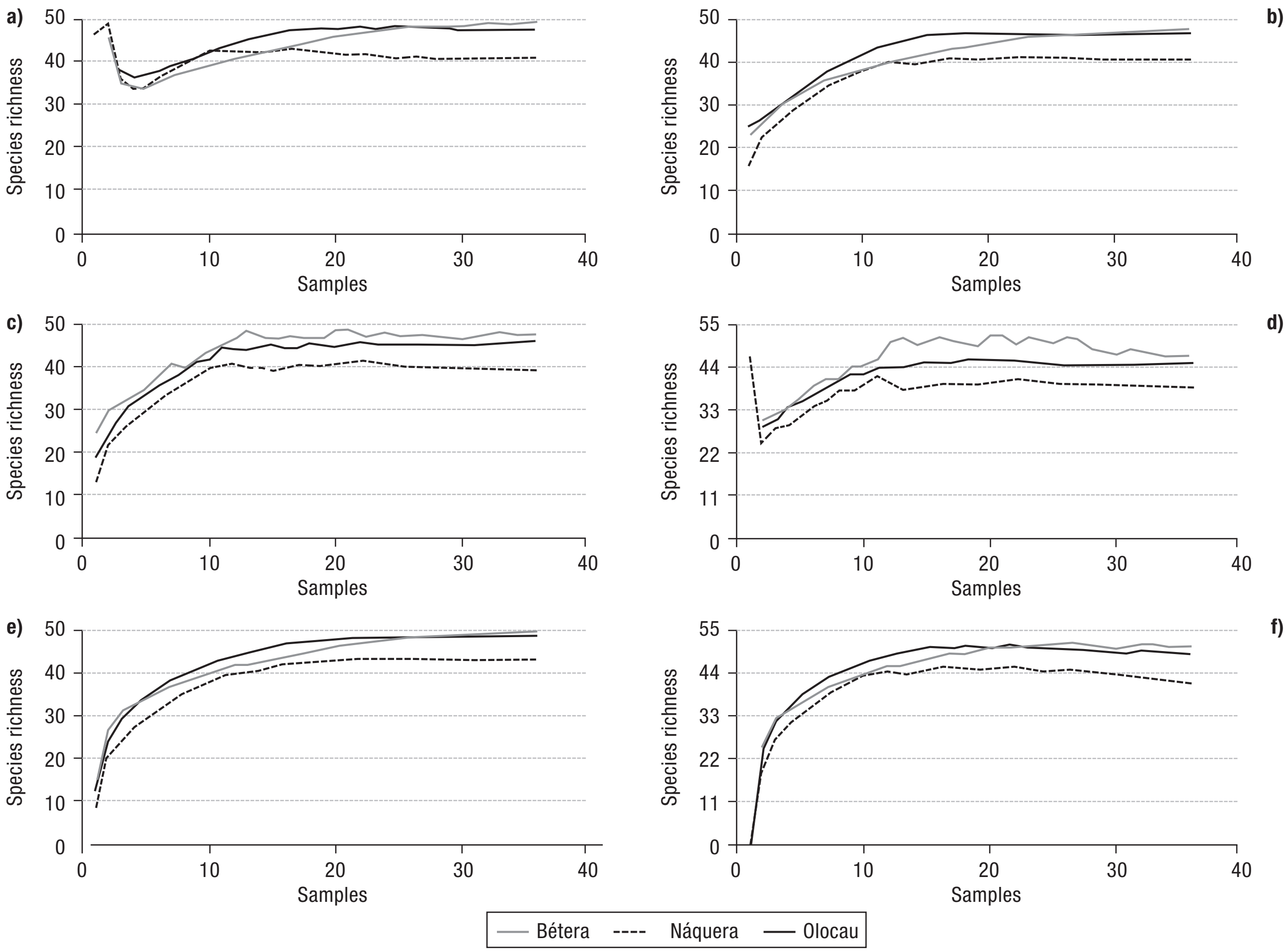

Figure 3. Mean values of observed species richness estimators, (a) ICE, (b) ACE, (c) Chao1, (d) Chao2, (e) Jackkinfe1 and (f) Jackknife2, at each sample increment for 50 random orders of sample addition, for the three citrus orchard sampled.

similar in Bétera and Olocau orchards. Diptera were more frequently found in Olocau, and Isopoda, Hymenoptera, Lepidoptera, and Orthoptera registered highest abundance in Bétera orchard.

Table 5. Total number of specimens belonging to different arthropod orders that can be used as prey by spiders, collected in pitfall traps in three citrus orchards in Valencia, Spain

	Bétera	Olocau	Náquera	Total
Isopoda	32,089	23,278	19,316	74,683
Diptera	10,774	16,168	7,642	34,584
Coleoptera	8,480	9,498	3,380	21,358
Hemiptera	4,179	4,255	592	9,026
Hymenoptera	1,568	846	237	2,651
Lepidoptera	963	178	65	1,206
Orthoptera	637	67	68	772
Total	50,210	54,290	27,920	144,280

Discussion

This work reveals the presence of a rich and abundant complex of spiders inhabiting the ground surface of citrus orchards. Ground-dwelling spiders play an important role as biological agents in many crops (Riechert and Lockley, 1984; Symondson, 2002b). Despite many studies about ground-dwelling spiders have been conducted in several citrus regions worlwide (Mansour et al., 1982; Mansour and Whitecomb, 1986; Green, 1999; Benfatto and di Franco, 2002), there is a lack of studies assessing the importance of this predatory group as biological control agents in citrus agroecosystems. Recent studies suggest that some ground-dwelling spider species could play an important role in the biological control strategies of some major citrus pests. Indeed, the most abundant spider found in this study, *P. cribata*, has been demonstrated to prey efficiently on third instar larvae and teneral adults of *C. capitata*, and on *Myzus persicae* (Sulzer) (Hemiptera: Aphididae) under laboratory conditions (Monzó *et al.*, 2009), and to use *C. capitata* as prey under field conditions, where other alternative preys occurs (Monzó *et al.*, 2010). The second most abundant spider, *Z. cesari*, which was mainly found in the Bétera orchard, belongs to a genus characterized as a specialized ant predator. It has been found that this species appears in this orchard as a predator of *Linepithema humile* Mayr (Hymenoptera: Formicidae) (Juan-Blasco *et al.*, 2010) one of the most important ant pests world-wide (ISSG, 2009). The data obtained in this work therefore will help to settle the basis for further citrus pest management studies using these predators in the western Mediterranean citrus region.

The demonstrated presence of spiders on the citrus-orchard ground throughout the year may ensure the permanent presence of predators even when a given pest has not yet arrived, thus helping to avoid pest outbreaks. Urbaneja *et al.* (2006) showed that, even in winter, when lower ground-spider activity was documented, there was still an important level of spider predation on *C. capitata* sentinel pupae.

Alvis (2003) studied spider communities appearing in the citrus canopy in the same citrus-growing area and found 55 spider species. The assemblage of canopy spiders differed totally from the ground-dwelling assemblage that we observed, with only a few minor species shared between them. In the canopy, Salticidae (40.7% of the total captures) and Theridiidae (35.7%) were the most abundant families (Alvis, 2003), whereas Lycosidae (32.0%), Gnaphosidae (22.0%) and Zodariidae (15.9%) were most abundant on the ground. Green (1999) drew similar conclusions in Australian citrus orchards when comparing the spider fauna of the canopy and the ground.

The existence of a clear mode in the species abundance distributions at Bétera and Náquera suggests that the sampled assemblages more closely approximate log normal theoretical distributions typical of stable assemblages rather than logarithmic series distributions, in which the mode is in the first octave indicating dominance by occasional, non-established species (Magurran, 2004). This is consistent with the prevalence of Lycosids and Gnaphosids in the assemblages we studied, which mainly move by walking and thus need a favourable habitat to establish their populations, rather than families such as Linyphids, that disperse by the wind and can colonize and dominate non-permanent spider assemblages (Luczak, 1979; Weyman *et al.*, 2002). These are indications that citrus-orchard ground offers a semipermanent habitat harbouring a rich and abundant arthropod fauna that enables more self-sustained spider populations to exist.

To our knowledge, this is the first survey of ground-dwelling spider fauna in citrus orchards in Spain. In other studies conducted in southern Italy (Benfatto and Di Franco, 2002) and Queensland, Australia (Green, 1999), 116 and 41species of ground-dwelling spiders were found in citrus orchards, respectively. In both studies, the most abundant family was also Lycosidae. The number of species collected in these different agroecosystems may be related to the different landscape composition. In our study, the orchards were located in a region with a predominance of citrus monoculture, and consequently with low landscape diversity. Less complex landscape are considered to host fewer numbers of predatory species and less diverse assemblages (Sunderland and Samu, 2000; Schmidt *et al.*, 2005). Increasing the amount of non-crop habitat that surrounds crop fields may increase spider diversity (Schmidt *et al.*, 2005).

Because all the non-parametric species richness estimators reached an asymptotic value with sampling addition, and gave similar predictions of species richness that were also similar to the estimated number of non-sampled species (S*), it can be concluded that species richness estimates accurately reflect the ground-dwelling spider assemblage diversity. The highest number of individuals found and species estimated was in Bétera followed by Olocau. Both orchards had a permanent plant cover crop in contrast to Náquera, where soil was maintained bare. The greatest number of alternative prey was also found in the orchards that had a plant cover crop. Indeed, Náquera had the lower number of pitfall traps captures for all the arthropod orders studied, including spiders. Also, there seems to be a more abundant arthropod fauna in Bétera (spontaneous plant cover crop) compared to Olocau (monoespecific cover of the grass *F. arundinacea*). This is especially evident with orders such as Hymenoptera, Lepidoptera and Orthoptera. The presence of plant species on the orchard ground may increase abundance and diversity of both phytophagous, because of greater structural complexity on the habitat and more abundant and diverse food resources, and predators, due to more alternative prey types and a greater variety of refuges (Sunderland and Samu, 2000; Marshall *et al.*, 2003). Bétera, with a spontaneous cover crop, had a more diverse plant composition than Olocau, with its more uniform cover crop (B. Belliure, IVIA, unpublished results). Náquera, with bare soil, had the simplest structural habitat. Suitable cover crop management may exert an important effect on spider assemblage composition and abundance, thus becoming a useful tool in conservation biological control strategies in citrus orchards. However, further research is needed to shed light on the role of cover crops in the management of ground-dwelling spiders.

In conclusion, ground-dwelling spiders constitute an important group among the predatory complex inhabiting the citrus orchard ground in terms of both abundance and species richness. Previous studies demonstrated that some spider species belonging to these assemblages are valuable in the control of some citrus pests. However, because of the great variety in predation opportunities that offers spider assemblages, their action as a whole could be of even greater importance in conservation biological control strategies in this citrus crop. For these reasons, suitable management of this predatory group; for example providing a cover crop, creating non-crop spider habitats or the increasing the selectivity of pesticides, would facilitate population increase and diversity, helping to optimize conservation biological control strategies in citrus. A challenge for future studies will be to enhance and preserve the populations of ground-dwelling spiders in order to achieve these goals.

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