

Cross-habitat usage by crop aphids and their parasitoids in the crop-noncrop interface in an organic vegetable farm

Uso del hábitat por áfidos y sus parasitoides en la interfase cultivo-vegetación silvestre en una granja orgánica

JAUREGUIBERRY, Pedro^{1, 2}; BUFFA, Liliana M.¹; DELFINO, Miguel A.¹

¹ Cátedra de Entomología, FCEFyN, Universidad Nacional de Córdoba, Argentina. lbuffa@efn.uncor.edu

² Present address: Instituto Multidisciplinario de Biología Vegetal (CONICET-UNC), Córdoba, Argentina. pedrojaureguiberry@efn.uncor.edu

ABSTRACT

Plant-aphid-parasitoid interactions and parasitism rates were assessed in adjacent cultivated and non-cultivated habitats in an organic vegetable farm in a chaco serrano woodland, Córdoba, Argentina. Seven aphid species on eight vegetable species were found in the cultivated habitat. *Macrosiphum euphorbiae* was present on all vegetable species. Four parasitoid species were recorded, of which *Diaretiella rapae* was the most common. It provided 21.32% of parasitism on *Brevicoryne brassicae*. In the non-cultivated habitat, 36 plant species hosted 22 aphid species and five parasitoid species. The aphid *Myzus persicae* was present on 17 plant species of eight different families. *Macrosiphoniella artemisiae* was the most abundant aphid species, with the associated *Aphidius* sp. being the most abundant parasitoid. *Aphidius polygonaphis* provided 10% of parasitism on *Uroleucon aeneus*. We report several wild plant species as important reservoirs of parasitoids, which are potential controllers of many pest aphid species.

KEY WORDS: biological control, ecosystem services, organic vegetable farming, parasitism, plant-aphid-parasitoid interactions, agro-ecology.

RESUMEN

Se estudiaron las interacciones planta-áfido-parasitoide y las tasas de parasitismo en ambientes cultivados y no cultivados adyacentes, en una granja orgánica de hortalizas en el chaco serrano de Córdoba, Argentina. Siete especies de áfidos fueron encontradas en las ocho especies de hortalizas estudiadas en el ambiente cultivado. *Macrosiphum euphorbiae* estuvo presente en todas las hortalizas. Se registraron cuatro especies de parasitoides, siendo *Diaretiella rapae* la más frecuente. Produjo 21,32% de parasitismo en *Brevicoryne brassicae*. En el ambiente no cultivado 36 especies de plantas hospedaron 22 especies de áfidos y cinco especies de parasitoides. El áfido *Myzus persicae* estuvo presente en 17 especies de plantas de ocho familias diferentes. *Macrosiphoniella artemisiae* fue el áfido más abundante, al igual que su parasitoide *Aphidius* sp. *Aphidius polygonaphis* produjo 10% de parasitismo en *Uroleucon aeneus*. Reportamos numerosas especies de plantas silvestres como importantes reservorios de parasitoides, los cuales son potenciales controladores de muchas especies de áfidos plaga.

PALABRAS CLAVE: control biológico, cultivo orgánico de hortalizas, interacciones planta-áfido-parasitoide, servicios ambientales, agroecología.

Correspondências para: pedrojaureguiberry@efn.uncor.edu

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Introduction

Presence of insect pests is one of the main constraints for horticultural production, since they cause severe losses in yields and quality of the fruit and vegetables produced. Aphids (Hemiptera: Aphididae) are one of the most widespread pests in agroecosystems (WELLINGS *et al.*, 1989). The incidence of these insects depends on different factors such as the species involved, the types and phenological stages of the crop host plants and other characteristics of the environment (MINEAU and McLAUGHLIN, 1996). Another key factor is the presence and abundance of the pests' natural enemies (MINEAU and McLAUGHLIN, 1996; LANDIS *et al.*, 2000). These enemies can be used as natural regulators that can significantly limit pest populations and therefore their impact (SCHMIDT *et al.*, 2004; FENG *et al.*, 2007).

Parasitoids (Hymenoptera: Braconidae) are an important group of aphid natural enemies and can considerably reduce aphid colony size (MOHAMED *et al.*, 2000; SCHMIDT *et al.*, 2003). Adult females oviposit single eggs into the bodies of aphid hosts, which turn into 'mummies' composed of the hardened exoskeleton of the aphid. The parasitoid larvae pupate inside the mummy and later emerge as nectarivorous adults (LÓPEZ CRISTOBAL, 1946).

The main constraint to effective pest-control through parasitoids is that parasitoids themselves may only manifest in large enough numbers to provide a pest control benefit after the aphid population has settled (STARÝ, 1988). This delay allows aphid population sufficient time to cause crop damage before parasitoids are able to have an impact (STARÝ, 1988). Fortunately almost all taxonomic groups of aphids, both on cultivated and native wild plants, are susceptible to parasitoids (TIZADO and NÚÑEZ PÉREZ, 1991), and most parasitoids are adapted to use a number of aphid species as hosts, which are related to those species classed as pests. These related species are often found in the crop itself or in non-

cultivated habitats near crops. They therefore represent appropriate alternative hosts, which could favour the survival of parasitoid populations during critical periods such as after harvests when pest aphid populations crash (STARÝ, 1993; TIZADO MORALES *et al.*, 1992).

Population dynamics and diversity of natural enemies are strongly influenced by crop structural attributes and management (e.g. crop rotations, presence of flowering weeds, genetic diversity) (ALTIERI and NICHOLLS, 2004; ROSCHEWITZ *et al.*, 2005). When less-modified habitats found on the edges of crops are preserved, they offer parasitoids a permanent source of food, shelter and reproduction sites by fostering a greater diversity of plants and host insects (VAN EMDEN, 1965; LEWIS, 1969; ALTIERI and NICHOLLS, 2004). These species can be suitable alternative hosts for natural enemies, capable of colonizing annual crops and controlling pests, reducing the probabilities of pest outbreaks (LANDIS *et al.*, 2000; TSCHARNTKE, 2000; SCHELLHORN and SILBERBAUER, 2003). For example cabbage and broccoli suffer less damage by aphids when they are intercropped with wild brassicaceae (LANDIS *et al.* 2000; PONTI *et al.*, 2007).

Studies on interactions between non-cultivated plants and their associated insect fauna could then provide guidelines for improving biological control in vegetable crops. Despite these kinds of crops being a very important activity in several regions of Argentina, little is known about plant-aphid-parasitoid interactions occurring on horticultural systems. The present study is an attempt to contribute to knowledge on the use of alternative host plants of economically important aphids on common vegetable crops.

The cross-habitat usage by crop aphids and their parasitoids in adjacent cultivated and non-cultivated plots in an organic vegetable farm is explored. Furthermore, aphids' parasitism rates in

the two different habitats are assessed. We expect to find alternative host plants in the non-crop habitat that might be considered as key reservoirs for plant-aphid-parasitoid interactions dynamics in the crop-noncrop interface in the study area.

Materials and Methods

Surveys were carried out in a farm located in El Manzano, Córdoba Province, Argentina (approximately 31°05'10,83"S, 64°17'17,40"W). The climate is temperate, with cold winters, warm summers and a rainy season from October to April. Total annual precipitation is approximately 725 mm. Mean temperatures of the coldest (July) and warmest (January) months are 18 °C and 8 °C respectively (CAPITANELLI, 1979). At 700m above sea level, the site belongs to the lower level of the chaco serrano woodland vegetation belt (Chaqueño Serrano district of LUTI et al., 1979). It is characterized by an open tree stratum, with native vegetation that includes short trees, mainly *Prosopis nigra*, *Celtis ehrenbergiana* and *Fagara coco*; thorny shrubs such as *Acacia caven*, *Condalia montana* and *Lycium cestroides*; herbs and epiphytes. Nevertheless, the crop area at the study site (i.e. cultivated habitat) (5ha in size) is surrounded by semi-natural vegetation (i.e. non-cultivated habitat), most of which is comprised of an herbaceous stratum with both annual and perennial herbs, with few trees and shrubs. Within the crop area there are four plots, each one containing one or two (depending on the sampling date) different vegetable crop species. Agricultural plots are farmed organically, with crop rotations including a one-year fallow or pasture every five years.

We performed biweekly surveys between February and September of 2004. A total of 17 surveys were carried out. Each survey involved the following:

a) In the cultivated habitat: among the existing

vegetable crops in all four plots 15 mature plants were randomly selected and sampled. Therefore the number of sampled plants for each vegetable crop species would depend on its abundance and in whether it was present or not in the date of the survey. The presence and abundance of aphids and/or parasitoid mummies in each plant was recorded. Samples were stored in plastic bags for further processing in the laboratory. The number of sampled plants for each vegetable crop species across the study is shown in table 1.

b) In the non-cultivated habitat: a representative area of the uncultivated habitat adjacent to each sampled crop was delimited and the same protocol as above was followed for 15 randomly selected wild plants (which were collected for subsequent taxonomic identification). The number of sampled plants for each wild plant species across the study is shown in table 2.

In the laboratory, aphids were placed in Khan tubes with 70% ethanol and later identified. Mummies found in the field were put in Petri dishes until the emergence of adult parasitoids. Once emerged, these were placed in Khan tubes with 70% ethanol and later identified. The percentages of parasitism for each aphid species were calculated by dividing the number of parasitoids that emerged from mummies by the sum of the number of aphids and emerged parasitoids.

Results

a. Cultivated habitat

a.1. Aphid-plant interactions

The vegetables species (grouped by family) sampled in this habitat were: Asteraceae: curled lettuce (*Lactuca sativa* L. var. *crispa* L.), red lettuce (*Lactuca sativa* L. var. *inybacea* (L.) Janchen) and rocket (*Eruca sativa* Mill.); Brassicaceae: radish (*Raphanus sativus* L.) and

Table 1. Abundance of aphids recorded in vegetable crops in an organic farm in Córdoba, Central Argentina. The number of sampled plants for each vegetable crop species is shown in the second column.

Host plant	Cultivated habitat							Total	
	n° of sampled plants	Aphid species							
		<i>Aphis craccivora</i>	<i>Aphis gossypii</i>	<i>Brevicoryne brassicae</i>	<i>Macrosiphum euphorbiae</i>	<i>Myzus persicae</i>	<i>Nasonovia ribisnigri</i>	<i>Uroleucon ambrosiae</i>	
<i>Beta vulgaris</i> var. <i>cicla</i>	50				83	6			89
<i>Brassica oleraceae</i> var. <i>capitata</i>	20			530	88	61			679
<i>Cucumis sativus</i>	35		1345		4				1349
<i>Eruca sativa</i>	20				69	13			82
<i>Lactuca sativa</i> var. <i>crispa</i>	30				482		42	13	537
<i>Lactuca sativa</i> var. <i>invbacea</i>	15				59		267		326
<i>Raphanus sativus</i>	60				160	183			343
<i>Vicia faba</i>	25	148			43				191
Total	255	148	1345	530	988	263	309	13	3596

cabbage *Brassica oleraceae* L. var. *capitata* L.; Chenopodiaceae: chard (*Beta vulgaris* L. var. *cicla* L.); Cucurbitaceae: cucumber (*Cucumis sativus* L.); Fabaceae: broad bean (*Vicia faba* L.).

Seven aphid species and four parasitoid species were found in this habitat (Figure 1). *Macrosiphum euphorbiae* (Thomas) and *Myzus persicae* (Sulzer) were the most broadly distributed aphid species (i.e. were present on more plant species), the former being found on all the studied vegetable species and the latter on four vegetable species. Furthermore *Aphis gossypii* Glover was the most abundant aphid in this habitat (Table 1). This aphid species together with *Aphis craccivora* Koch, *Uroleucon ambrosiae* (Thomas) and *Brevicoryne brassicae* (L.) each one had a different vegetable species as its only host plant. At last, *Nasonovia ribisnigri* (Mosley) was found on the two lettuce species sampled in this habitat (Figure 1).

a.2. Aphid-parasitoid interactions

The most broadly distributed parasitoid was *Diaretiella rapae* (McIntoch), which parasitized three aphid species on five different host plants, mainly *B. brassicae* on *B. oleraceae* var. *capitata* (Figure 1).

Aphidius ervi (Haliday) was recorded on the aphid *M. euphorbiae* on five vegetable species, mainly curled lettuce. It also parasitized *M. persicae* on three vegetable species and *N. ribisnigri*, being curled lettuce the main host plant (Figure 1). The remaining parasitoid species found were *Aphidius matricariae* (Haliday), parasitizing *A. gossypii* on cucumber, and *Lysiphlebus testaceipes* (Cresson), found on *M. euphorbiae* on *V. faba* (Figure 1).

Five of the seven aphid species found in this habitat were parasitized. Percentage of parasitism

Table 2. Abundance of aphids recorded in a non cultivated habitat adjacent to vegetable crops in an organic farm in Córdoba, central Argentina. The number of sampled plants for each plant species is shown in the second column. Only the plant species that hosted aphids are reported.

Host plant	n° of sampled plants	Non-cultivated habitat																Total						
		Aphid species																						
		<i>Aphis gossypii</i>	<i>Aphis apravoza</i>	<i>A. brassicae</i> sp.	<i>Brevicoryne brassicae</i>	<i>Brevicoryne brassicae</i>	<i>Brachycaudus thabae</i>	<i>Capitophora nectareae</i>	<i>Caecovorus</i> sp.	<i>Ceratolepis agropoli</i>	<i>Euscelinus elegans</i>	<i>Hyperomyza maculipes</i>	<i>L. pectus</i> sp.	<i>Macropodaphis artemisiae</i>	<i>Macropodaphis</i> sp.	<i>Macropodaphis</i> sp.	<i>Macropodaphis</i> sp.							
<i>Achillea millefolium</i>	5													2235				2235						
<i>Baccharis</i> sp.	1			7														18						
<i>Bidens pinnata</i>	5	57	71															128						
<i>Brassica nigra</i>	4	5										13	25				100	149						
<i>Brassica oleracea</i>	1																	46						
<i>Carduus hirsutus</i>	2	30													31		71	132						
<i>Cirsium</i> sp.	4					137												260						
<i>Cestrum parlati</i>	2																85	99						
<i>Chenopodium</i> sp.	2						30											30						
<i>Chenopodium</i> sp.	1														21			21						
<i>Colquhounia ovalifolia</i>	2															70		70						
<i>Conium maculatum</i>	1	37																37						
<i>Cotoneaster integerrimus</i>	1																	30						
<i>Corylus avellana</i>	1	400																400						
<i>Dipsacis tenuifolia</i>	1					50												50						
<i>Eupatorium wislizeni</i>	1	7			8													15						
<i>Galium aparine</i>	1																	5						
<i>Galium aparine</i>	1	30																30						
<i>Geranium robertianum</i>	1																130	130						
<i>Leontodon tataricus</i>	5						136											136						
<i>Lythrum salicaria</i>	1																	207						
<i>Malvastrum coccineum</i>	2	9															17	35						
<i>Malvastrum integrifolium</i>	1																	16						
<i>Mercurialis annua</i>	4	20																33						
<i>Medicago lupulina</i>	1																	144						
<i>Medicago lupulina</i>	2	5																107						
<i>Oxalis stricta</i>	1																	27						
<i>Pastinaca sativa</i>	2																	27						
<i>Plantago lanceolata</i>	1	47																474						
<i>Plantago lanceolata</i>	1	47																47						
<i>Sisymbrium officinale</i>	1																	8						
<i>Setaria argentea</i>	1																	15						
<i>Setaria fabiana</i>	1	5																5						
<i>Stachys recta</i>	1																	113						
<i>Stachys recta</i>	1	4																4						
<i>Urtica dioica</i>	2			7														7						
<i>Xanthoxylum</i>	1																	11						
Total	69	672	71	7	25	50	257	136	251	35	33	113	13	2235	83	70	40	1441	316	152	46	260	16	6068

ranged from 21.32% (on *B. brassicae*) to 0.07% on *A. gossypii* (Table 3). *A. craccivora* and *U. ambrosiae* had no parasitoids.

b. Non-cultivated habitat
b.1. Aphid-plant interactions

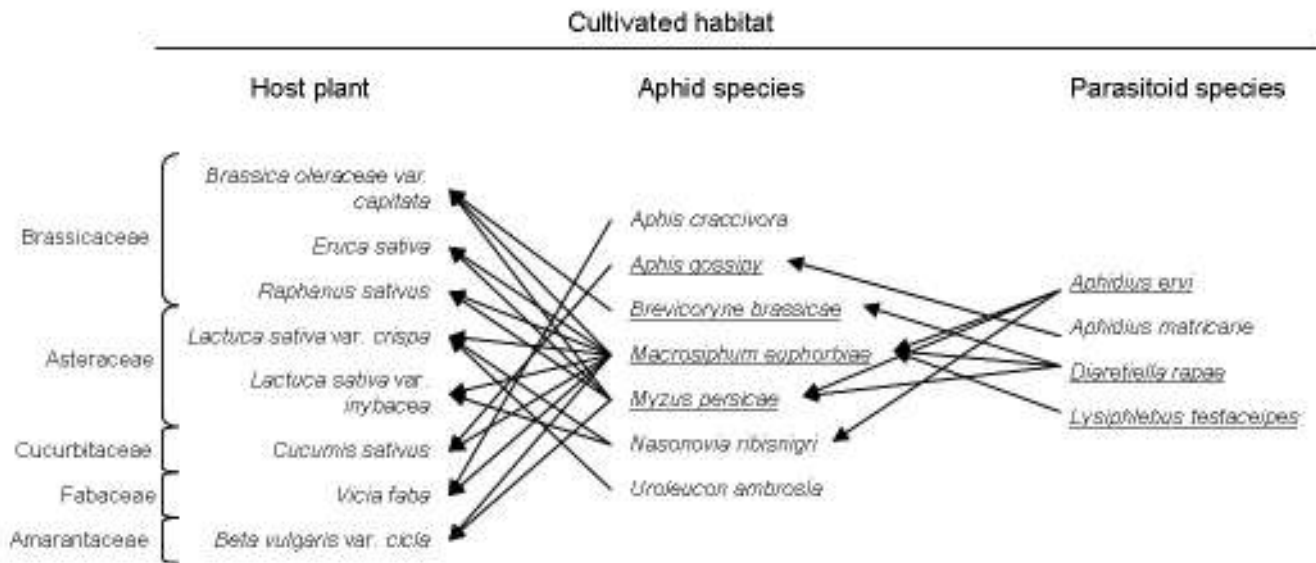


Figure 1. Plant-aphid-parasitoid interactions in a vegetable crop surrounded by non-cultivated land in an organic farm in Córdoba, central Argentina. Underlined aphid and parasitoid species are common to both habitats (i.e. cultivated and non-cultivated; see Figure 2).

In this habitat, aphids and/or mummies were found on 36 plant species belonging to 14 different families (Figure 2). Furthermore, 22 aphid species and five parasitoid species were recorded (Figure 2).

The most broadly distributed aphid was *M. persicae*, which was present in 17 plant species of eight different families (Figure 2). Despite its broad distribution, most of individuals were hosted by

three plant species: *Pastinaca sativa* L. (Apiaceae), *Bidens pilosa* L. (Asteraceae) and *Lycium cestroides* Schl. (Solanaceae) (Table 2). Furthermore the most abundant aphid was *Macrosiphoniella artemisiae* (Boyer de Fonscolombe). Its colonies were very dense and they were distributed in both stems and leaves of *Artemisia abrotanum* L., its only host plant (Figure 2 and Table 2).

Table 3. Percentages of parasitism by microhymenopteran (Hymenoptera: Braconidae) on shared (*B. brassicae*; *euphorbiae*; *M. persicae* and *A. gossypii*) and non-shared (*N. ribisnigri*; *U. aeneus*; *C. elaeagni*; *M. artemisiae*) aphid species found in adjacent cultivated and non-cultivated habitats in an organic farm in Córdoba, Argentina. Abundance of aphids is given in parenthesis.

Aphid species	% of parasitoidism	
	Cultivated habitat	Non-cultivated habitat
<i>Aphis gossypii</i>	0.07 (1345)	0.0 (672)
<i>Brevicoryne brassicae</i>	21.32 (530)	0.0 (50)
<i>Macrosiphum euphorbiae</i>	6.18 (988)	5.68 (88)
<i>Myzus persicae</i>	4.17 (263)	0.42 (144)
<i>Nasonovia ribisnigri</i>	0.32 (309)	-
<i>Capitophorus elaeagni</i>	-	1.5 (257)
<i>Uroleucon aeneus</i>	-	1.1 (260)
<i>Macrosiphoniella artemisiae</i>	-	1.22 (2205)

Cross-habitat usage by crop aphids

A. gossypii was found on 13 plant species, belonging to 8 different families but *Conyza bonariensis* (L.) Cronquist. (Asteraceae) stands out as its main host plant, as it hosted most of the

individuals (Table 2). *B. brassicae* also had only one host plant in this habitat, *Diplotaxis tenuifolia* (L.) DC. (Brassicaceae); whereas *M. euphorbiae* was found on four different plant species (Figure 2).



Figure 2. Plant-aphid-parasitoid interactions in a non-cultivated habitat adjacent to a vegetable crop in an organic farm in Córdoba, Central Argentina. Underlined aphid and parasitoid species are common to both habitats (i.e. cultivated and non-cultivated; see Figure 1).

b.2. Aphid-parasitoid interactions

Only five out of the 22 aphid species found in this habitat were parasitized. The highest percentage of parasitism was that of *A. polygonaphis* on *Uroleucon aeneus* Hille Ris Lambers (10 %) (Table 3). The aphids found on *Chaptalia* sp. were parasitized by three different species of parasitoids (*A. ervi*, *L. testaceipes*, and *D. rapae*). Furthermore aphids found on *B. pilosa* and *A. abrotanum* were parasitized by *Aphidius* sp., the most abundant parasitoid in this habitat; whereas the aphids found on *Carduus* sp. were parasitized by *Aphidius polygonaphis* Fitch (Figure 2).

The other plant species that hosted parasitized aphids were *Capsella bursa-pastoris* (L.) Medikus, *B.nigra* (Brassicaceae) and *Chenopodium* sp. (Chenopodiaceae). In both brassicaceae the parasitoid found was *D. rapae*, parasitizing *M. euphorbiae* and *M. persicae* on *C. bursa-pastoris*, and *M. persicae* and *M. euphorbiae* on *B. nigra* (Figure 2). On *Chenopodium* sp. the parasitoid was *A. ervi*, which was found parasitizing *M. euphorbiae*.

Aphidius sp. was the most abundant parasitoid. Most of individuals were parasitizing the aphid *M. artemisiae* on *A. abrotanum*. At last *A. polygonaphis* was found parasitizing the aphid *U. aeneus* on *Carduus* sp.

c. Comparison between habitats

Both habitats shared only four of the 25 aphid species found across both habitats. These were *A. gossypii*, *M. euphorbiae*, *M. persicae* and *B. brassicae*. Percentages of parasitism were higher in the cultivated plots in the four species (Table 3). The most noticeable difference concerned *B. brassicae*, the aphid with the greatest parasitism in

cultivated plots (21.32%) and no parasitism in non-cultivated plots. *M. persicae* also showed considerable difference between habitats (4.17% and 0.42% in the cultivated and non-cultivated plots respectively). On the other hand, *M. euphorbiae* had similar values in both habitats (6.38% and 5.68%) and *A. gossypii* had very low parasitism in both habitats (0.07% and 0%) (Table 3).

Phenologies of plant species that hosted parasitoids in the non-cultivated habitat are shown in figure 3 (following MARZOCCA, 1979). It is important to mention that phenology of these species may vary quite significantly depending on precipitation and location of individuals.

Discussion

All four aphid species shared between habitats (out of a total of 25) are known to be capable of colonizing a broad range of alternative hosts, including economically important cultivated plants, which are rarely related to their primary host (DIXON, 1987; BLACKMAN and EASTOP, 2000). The preference of aphids for colonizing different plant species in both studied habitats is supported by research elsewhere (STARÝ and DELFINO, 1986; STARÝ, 1993; BLACKMAN and EASTOP, 2000).

Despite the broad host use of *M. persicae* in the non-cultivated habitat, it was parasitized by *D. rapae* only, and then only when its colonies were located on brassicaceae. This is despite this aphid being susceptible to parasitism by several parasitoid species on different host plants (STARÝ and DELFINO, 1986; STARÝ, 1993). As reported by Vinson (1976), it is often the case that the plants in which aphid colonies are established play an important role in determining if those aphids will be parasitized or not. In the current study *D. rapae* was responsible for a notably high level of aphid parasitism on cabbage. This is consistent with the

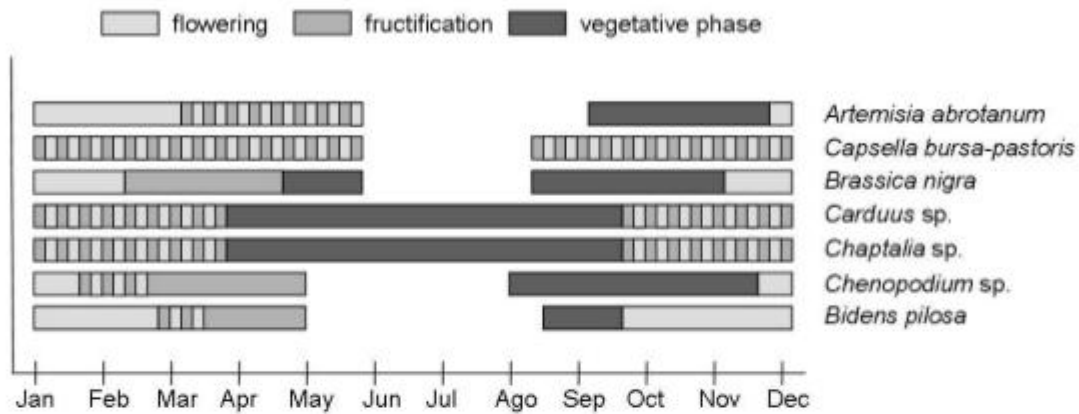


Figure 3. Phenology of plant species that hosted aphid parasitoids in a non-cultivated habitat adjacent to vegetable crops in an organic farm in Córdoba, Argentina (following Marzocca, 1979) (see text for details).

fact that this parasitoid preys mainly on *M. persicae* and *B. brassicae* (HORN, 1989; STARÝ and CERMELI, 1989), which were two of the three aphid species found on cabbages in this study.

The greater parasitism of shared aphid species in the cultivated habitat may be due to the influence of adjacent non-cultivated area. Several authors suggest that dynamics of insect populations and the structure of communities within cultivated areas are greatly influenced by the nearby non-cultivated areas. This is reportedly due to factors such as food availability (water, pollen and prey), microclimatic conditions, habitat resources (reproduction sites, shelter), inter-specific competition and presence of other organisms such as hiperparasitoids and predators (TSCHARNTKE, 2000; ALTIERI and NICHOLLS, 2004; ROSCHEWITZ et al., 2005). According to Hawkins and Lawton (1987) parasitoids respond strongly to these factors. Furthermore these factors result in more architecturally complex plant communities, which have more insect species living on them (HAWKINS and LAWTON, 1987;

BROWN, 1991).

Percentage of parasitism can also be directly related to the abundance of host aphids (THIES et al., 2005). Therefore the absence of parasitoids in most of aphid species in the non-cultivated habitat can be explained by very low aphid abundance on certain host plants, whereas heavily parasitized aphids were found in colonies with high number of individuals, both in the cultivated and non-cultivated habitats (Table 2 and 3).

Interestingly, a few host plants in the non-cultivated habitat hosted parasitized aphids that do not cause damage to crops (BLACKMAN and EASTOP, 2000), which make these plants highly suitable for biological control. This was the case of *Chaptalia sp.*, *Carduus sp.* and *A. abrotanum* (hosting the parasitized aphids *C. elaeagni*, *U. aeneus* and *M. artemisiae* respectively). Therefore, these plants could act as reservoirs of *L. testaceipes*, *A. ervi*, *D. rapae*, *A. polygonaphis* and *Aphidius sp.* These parasitoids are all potential controllers of many aphid species.

Moreover, the brassicaceae *C. bursa-pastoris*

and *B. nigra* should be considered as important alternative host plants. Despite aphids found upon them were also found in the cultivated habitat, their presence could insure a stable and permanent population of *D. rapae* (e.g. PONTI et al., 2007), mentioned by Zhang and Hassan (2003) as a key parasitoid for reducing high population of *B. brassicae* on cabbage.

Most of the year plant species mentioned as alternative host of aphids and parasitoids in the non-cultivated habitat co-exist with crop species (Figure 3). This, together with the flexible phenology of most of the crop species (i.e. they can be grown almost year round) should allow non-cultivated plant species to be effectively used as alternative host for aphids and their parasitoids. As we accumulate knowledge regarding alternative hosts of parasitoids of pest aphids, we will be better able to incorporate agroecological strategies to optimize natural pest-control, including in conventional crop production systems.

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