doi:10.14720/aas.2024.120.1.17047 Original research article / izvirni znanstveni članek

Interactions between aphids and aphidophages in citrus orchards in the Chlef region (North West of Algeria)

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Received December 09, 2023; accepted January 11, 2024.
Delo je prispelo 9. decembra 2023, sprejeto 11. januarja 2024.

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Abstract: The objective of this study is to inventory and identify the different species of aphids and aphidophages associated with them in citrus orchards in the Chlef region (Algeria) in order to promote predation and parasitism interactions for the ultimate purpose of biological control of these formidable pests. Surveys are conducted twice a month for an entire year. For sampling, we used yellow sticky traps, yellow pans, and visual determination. This study allowed us to identify seven species of aphids and 34 species of aphidophages, including 30 predator species and 4 parasitoid species. The most abundant aphids are *Aphis spiraecola* (Patch, 1914) and *Aphis gossypii* (Glover, 1877), while the most common aphidophages are *Episyrphus balteatus* (De Geer, 1776), *Chrysoperla carnea* (Stephens, 1836), *Coccinella septempunctata* (Linné, 1758), *Aphidoletes aphidimyza* (Rondani, 1847) and *Lysiphlebus fabarum* (Marshall, 1896). In terms of frequency, aphidophages are dominated by ladybugs, followed by lacewings, then syrphids, then bugs, and aphid midges in last place. The diversity of the aphidophages fauna is not very important, but the highest values are observed towards the end of April. Predation activities in the study area extend from the end of March to November. Aphidophages associated with aphids are divided into generalists and specialists. Specialist aphidophages show preferences for certain prey over others, in the case of aphid diversity according to both intrinsic and extrinsic factors.

Key words: aphids, aphidophages, citrus, natural enemies, Chlef region

Interakcije med listnimi ušmi in afidofagi v nasadih citrusov v regiji Chlef (severozahod Alžirije)

Izvleček: Cilj te raziskave je bil popisati in identificirati različne vrste listnih uši in z njimi povezane afidofage v nasadih citrusov v regiji Chlef (Alžirija), da bi spodbudili interakcije plenjenja in parazitizma za končni namen biotičnega zatiranja teh nevarnih škodljivcev. Raziskave so potekale dvakrat mesečno skozi celo leto.Za vzorčenje smo uporabili rumene lepljive pasti, rumene posode in vizualno določanje. Ta študija nam je omogočila identifikacijo sedmih vrst listnih uši in 34 koristnih vrst, vključno s 30 vrstami plenilcev in 4 vrstami parazitoidov. Najštevilčnejši vrsti listnih uši sta *Aphis spiraecola* (Patch, 1914) in *Aphis gossypii* (Glover, 1877) medtem, ko so najpogostejši plenilci *Episyrphus balteatus* (De Geer, 1776), *Chrysoperla carnea* (Stephens, 1836), *Coccinella septempunctata* (Linnaeus, 1758), *Aphidoletes aphidimyza* (Rondani, 1847) in *Lysiphlebus fabarum* (Marshall, 1896). Glede na pogostnost prevladujejo med plenilci polonice, sledijo jim čipkarke, nato trepetavke, nato plenilski hrošči, na zadnjem mestu so plenilske hržice. Raznolikost afidofagne favne ni zelo pomembna, vendar so največje vrednosti opažene proti koncu aprila. Dejavnosti plenjenja na območju študije trajajo od konca marca do novembra. Afidofagi, povezani z listnimi ušmi, se delijo na generaliste in specialiste. Afidofagi specialisti kažejo preferenco za določen plen, v primeru raznolikosti listnih uši glede na notranje in zunanje dejavnike.

Ključne besede: listne uši, afidofagi, agrumi, naravni sovražniki, Chlef regija

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1 INTRODUCTION

Citrus fruits are one of the most important fruit tree crop in the world. They are cultivated in 168 countries on an area of 12.7 million hectares (FAOSTAT, 2022).

Algeria, due to its geographical location, is one of the world's leading producers of citrus fruits. The country has a total area of 77,895 ha with a production of 2 million tons (MADR, 2021).

Chlef is one of the most productive regions in the country, unfortunately, this crop hosts several pests and diseases. Aphids are considered to be not only among the most formidable pests of citrus (Ait-Amar et al., 2022), but also among the main vectors of phytopathogenic viruses (De Moya-Ruiz et al., 2023). They are phytophagous and all piercing-sucking. This mode of nutrition can lead to various reactions in the plant, both to the bite and to the toxicity of the saliva (Herrbach, 2022). Their honeydew allows the development of fungi that hinder the photosynthesis of the plant and its chlorophyll state (Hullé et al., 1999).In turn, aphids provide food for a variety of predatory species. This natural chain helps to maintain biological balance. This balance can be disrupted by the decline in the diversity of entomophages. It is in this approach that Straub & Snyder (2006) decline the importance of the relationship between the biodiversity of predators and biological control of bio-aggressors, as studies have shown that predators can complement or interfere with each other (Snyder & Ives, 2003; Finke & Denno, 2004).

In our study region, this auxiliary fauna is unfortunately poorly studied and still poorly known. In this context, the present study consisted of a survey of the predators of aphids on citrus as well as the aphidophages associated with them in one of the largest citrus-growing regions of Algeria. This opens the way for other studies on the impact of the predation of each of these entomophages on citrus pest aphids and facilitates the control of these pest populations by the implementation of sustainable biological pest management strategies.

2 MATERIALS AND METHODS

2.1 DESCRIPTION OF THE STUDY SITES

Three sites were selected for this study, the first orchard is a clementine orchard of the Montreal variety, 15 years old and located in Ouled Fares (Latitude: 36.2328, Longitude: 1.24028 36° 13′ 58″ North 1° 14′ 25″ East). It is located at an altitude of 136 meters and covers an area of 7 hectares. The second orchard is a Thomson Navel orange orchard, 21 years old and located in Ouled Abbes (Latitude: 36.2167, Longitude: 1.48333 36° 13′ 0″ North, 1° 28′ 60″ East). It is located at an altitude of 151 meters and covers an area of 3 hectares. The third orchard is a Washington Navel orange orchard, 19 years old and located in Labiodh Medjadja (Latitude: 36.25, Longitude: 1.4 36° 15′ 0″ North, 1° 24′ 0″ East) (Fig 1). It is located at an altitude of 196 meters and covers an area of 5 hectares. Chlef's climate is warm and temperate, of the Mediterranean type (Köppen classification: Csa). All three orchards are irrigated by a drip irrigation system that also provides fertilizer and pesticide applications. The soils in the study area (Chlef) are generally characterized by a high degree of homogeneity and agricultural aptitude, and are predominantly clay-loam (ABH; Chelliff Zahrez, 2003).

2.2 SAMPLING METHOD

This study was conducted between September 2021 and August 2022 in 3 citrus orchards in the Chlef region. This study consists of identifying and classifying the different types of aphids and their natural enemies present in citrus orchards in the study region. For this, we used three sampling methods, which are described below and we spread the prospections over the whole year in order to offer ourselves the chance to find more insects and other auxiliary arthropods regardless of their biological characteristics.

2.2.1 Sticky yellow traps

The installation of traps allows to follow the flight activity of the different species and to know precisely which periods of the year this activity will take place. The

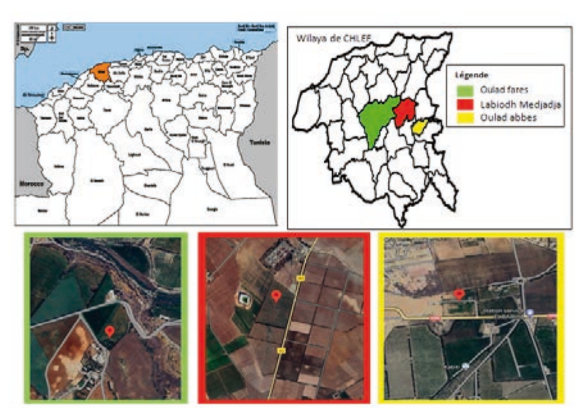

Figure 1: Geographic location of the experimental sites

flight phase of aphids plays an important role in the dispersal of species, in the search for host plants, and in the transmission of viral diseases.

In order to control all of these phenomena, it was necessary to carry out an air sampling by capturing winged aphids with freely moving yellow sticky traps (Hullé, 2010). Five yellow traps per orchard were placed at the four cardinal corners and in the center for a representative sampling of the orchard. Every 15 days (2 weeks), the previously installed traps are retrieved at the same time that new traps are installed in other parts of the orchard, so that the sampling is spread over the entire study area. Each retrieved trap is wrapped in a transparent plastic film to preserve all the trapped insects. In the laboratory, aphids and aphidophagous insects are collected and placed in test tubes filled with 70 °C ethyl alcohol for later identification.

2.2.2 Hand gathering of shoots

To count and identify the different species of aphids, their developmental stages, and their natural enemies, we carried out hand-gathering of shoots. To do this, at each sampling (2 per month), 10 trees are randomly selected and distributed across the different orientations of the orchard. From each tree, 5 shoots are randomly collected along the entire diagonal of the orchard (east, west, north, south, and center) and transported in transparent bags to the laboratory, where immediate identification is undertaken before the plants dry out. Individuals whose identification is difficult or doubtful are preserved for later identification or confirmation.

2.2.3 The yellow basins

These are circular plastic basins 20 cm in diameter that were placed at the level of the trees between the leaves and branches at an average height of 1 m above the ground. The basins were filled to ¾ with soapy water, which helped to fix the insects inside the basins. This type of trap captures not only winged aphids, but also their natural enemies, notably parasitoid Hymenoptera and other predatory insects. The trapped insects were collected every month in small plastic tubes containing 75 % alcohol, and counting and identification were carried out in the laboratory.

2.3 METHOD OF DATA ANALYSIS

2.3.1 Ecological diversity indices

To interpret the results, we based our analysis on the calculation of ecological indices of composition, such as total richness (S), centile frequency, and constancy, as well as ecological indices of structure, such as the Shannon-Weiner index H', evenness, and Simpson's index.

2.3.1.1 Ecological indices of composition

- Total richness:

According to Guillaum et al. (2009), richness tells us about the elements present in a given space. It is expressed by the number of species of the population considered in a given ecosystem (Ramade, 1984).

- Relative abundance of centile frequency (%):

According to Dajoz (1985), it is the percentage of individuals of a species compared to the total number of individuals. It is calculated by the following formula:

$$F.C.\% = \frac{ni}{N} \times 100$$

With: ni: Number of individuals of a species and N: Total number of individuals.

- Coefficient of abundance-dominance or frequency of occurrence

It is expressed as a percentage of the number of statements containing species i taken into consideration, divided by the total number of statements (Dajoz, 2003).

$$C = \frac{i}{N} \times 100$$

C: is the number of statements containing the species studied and N: is the total number of statements carried out.

Depending on the value of C, the following categories are distinguished:

- Very frequent or omnipresent species if C = 100 %.

- Constant species if 75 % < C < 100 %.
- Regular species if 50 % < C < 75 %.
- Accessory species if 25 % < C < 50 %.
- Accidental species if 5 % < C < 25 %.
- Rare species if C < 5 %.

2.3.1.2 Ecological structure indices

- The Shannon-Weaver diversity index

The Shannon-Weaver diversity index is considered to be the best index of diversity; it is calculated as follows (Blondel, 1979; Barbault, 1993):

$$H' = \Sigma p_i log_2(p_i)$$

H' is the diversity index expressed in bits, and pi is the proportional abundance or percentage abundance of a present species (pi = ni/N). Thus, a community will be more diversified the larger the H' index is. The maximum diversity (H'max) corresponds to the highest possible value of the population and translates to a heterogeneous population for which all individuals of all species are distributed equally.

It is calculated by the following formula:

$$H'max = \log 2\,(S)$$

S: is the total richness or the total number of species present.

- The Pielou evenness index

The Shannon index is often accompanied by the Pielou evenness index (J), or equipartition index (E) (Blondel, 1979). It is expressed as the ratio between the observed diversity and the theoretical maximum diversity and is calculated as follows:

$$E = H'/Hmax$$

E being the evenness, H' is the observed diversity index and H'max is the maximum diversity index expressed in bits.

The value of E varies from 0 to 1. It tends towards 0 when the population is composed of a few species and many individuals. When this value tends towards 1, it translates to a population represented by many species with approximately the same number of individuals. The high diversity values reflect the presence of a large number of aphidophages in the agrosystems studied, so biological regulation of aphid pests by their natural enemies would be of great benefit.

- The Simpson index

The Simpson index measures the probability that two individuals selected at random belong to the same species and is defined by the formula:

$$L = \Sigma\, ni(ni-1)/N(N-1)$$

Where Ni is the number of individuals of the given species and N is the total number of individuals.

This index is inversely proportional to diversity. As a result, another formulation has been proposed to establish an index directly representative of heterogeneity by subtracting the Simpson index from its maximum value. This new formulation constitutes the Simpson diversity index, which is expressed by the formula D = 1 - L. Therefore, this index varies from 0 (minimum diversity) to 1 (maximum diversity) (Ramade, 1984).

2.3.2 Statistical analysis (AFC)

The results of the presence-absence of the different species of aphids and those of the entomophages during the surveys carried out in the study environments were the subject of a correspondence factor analysis (AFC) using a trial version of XlSTAT. This latter allows the structure of the data to emerge, the way in which the modalities of each variable are situated in relation to each other, in a differential and relational way. According to Escoffier and Pages (2008), correspondence factor analysis can, on different types of data, describe the dependence or correspondence between two sets of characters. For the present study, this analysis allows us to investigate the affinities between aphid species and the aphidophagous insects that are associated with them in the agrosystems studied during the survey period. In other words, we can identify the aphids that are most preferred by each predator, the impact of predation by a given natural enemy at a given time or period, or the interactions between aphidophagous species (competition, association, etc.). This information is necessary for the selection of effective auxiliaries for use in one of the desired biological control methods (conservation, introduction, or augmentation) or for their use in an integrated pest management process.

3 RESULTS

3.1 THE APHIDS

3.1.1 The aphid fauna found in the study environments

Through our surveys conducted over a full year, seven different species of aphids distributed over three different genera were identified. The genus *Aphis* is represented by *Aphis spiraecola*, *Aphis gossypii*, *Aphis faba* and *Aphis nerii* (Boyer De Fonscolombe, 1841).

The genus *Toxoptera* is represented by *Toxoptera citricida* (Kirkaldy 1907) and *Toxoptera aurantii* (Boyer de Fonscolombe, 1841)**.** Finally, the genus *Myzus* is represented by *Myzus persicae* (Sulzer, 1776) (Table 1).

3.1.2 The total richness, and the relative abundance of aphid populations during the surveys conducted

The results of Table 3 on the specific richness, dominance, and centile frequency of citrus-damaging aphids in the Chlef region showed that the greatest infestations are noted during the autumn and spring periods. In fact, at the end of October, we recorded a very large aphid population reaching 5074 individuals (17.37 %). This population declines significantly before starting to increase again to reach very high levels exceeding 8000 individuals (28.45 %) by the end of May, then they disappear again from the end of June. It should be noted that during the periods from December to February and from the end of June to the end of September, aphids were completely absent in the study areas.

3.1.3 Total richness, relative abundance, and occurrence frequency of aphid species in the Chlef region

The results of Table 2 show that *Aphis gossypii* and

Table 2: Specific richness and centile frequency of aphids during the surveys

Date	Taxa_S	Effective	frequency %
10 /9	0	0	0
25 /9	2	8	0,03
10 /10	5	666	2,28
25 /10	6	5074	17,37
10 /11	2	928	3,18
25 /11	1	65	0,22
10 & 25 /12	0	0	0
10 & 25 /1	0	0	0
10 & 25 /2	0	0	0
10 /3	0	0	0
25 /3	2	776	2,66
10 /4	3	386	1,32
25 /4	8	1215	4,16
10 /5	7	7609	26,05
25 /5	8	8311	28,45
10 /6	6	4171	14,28
25 /6	0	0	0
10 & 25 /7	0	0	0
10 & 25 /8	0	0	0
Total	6	29209	100

Table 1: The aphid fauna recorded in the three citrus orchards surveyed

Families	Subfamilies	Tribe	genus	Species
Aphididae	Aphidinae	Aphidini	*Aphis*	*Aphis spiraecola* (Patch, 1914) *Aphis gossypii* (Glover,1877) *Aphis nerii* (Boyer De Fonscolombe, 1841) *Aphis fabae* (Scopoli, 1763)
			Toxoptera	*Toxoptera aurantii* (Boyer de Fonscolombe, 1841) *Toxoptera citricida* (Kirkaldy 1907)
		Macrosiphini	*Myzus*	*Myzus persicae* (Sulzer, 1776)

Aphis spireacola are the two most abundant species in citrus orchards in the Chlef region, with a richness of 12,933 and an abundance of (50.16 %) for the first species, and a richness of 12,585 corresponding to an abundance of (48.81 %) for the second. The other species are much less abundant, with a richness not exceeding 147 individuals and rates below 1 %.

In terms of occurrence, *Aphis. gossypii* and *Aphis. spireacola* were found to be regular species, *T. aurantii* was found to be an accidental species, while the other species are rare in our study areas.

3.2 APHIDOPHAGES

3.2.1 Aphidophages associated with aphids recorded in the study orchards

Thirty-four species of aphidophages that accompany aphids in their emergence and are involved in the biological regulation of their populations were also identified (Table 5). They are divided into 30 predators and 4 parasitoids, composed mainly of insects and dominated by beetles (13 species), hymenopterans (6 species), and

Table 3: Richness, abundance, and dominance of different aphids collected in citrus orchards in the Chlef region

Settings	*A. spiraecola*	*A. gossypii*	*T. aurantii*	*M. persicae*	*A. fabae*	*T. citricida*	*A. nerii*
Richness	14257	14651	167	102	17	4	11
Abundance (%)	48,81	50,16	0,57	0,35	0,06	0,01	0,04
Constancy	Accessory	Accessory	Accessory	Accidental	Accidental	Rare	Accidental

Table 4: Abundance of aphid species during the different surveys

	Species							
Date	*A. spiraecola*	*A. gossypii*	*T. aurantii*	*M. persicae*	*A. fabae*	*T. citricida*	*A. nerii*	Total
10/9	0	0	0	0	0	0	0	0
25/9	2	6	0	0	0	0	0	8
10/10	274	380	12	0	0	0	0	666
25/10	2799	2231	26	18	0	0	0	5074
10/11	491	405	21	11	0	0	0	928
25/11	27	38	0	0	0	0	0	65
10 &25/12	0	0	0	0	0	0	0	0
10 & 25/1	0	0	0	0	0	0	0	0
10 & 25/2.	0	0	0	0	0	0	0	0
10/3	0	0	0	0	0	0	0	0
25/3	277	496	3	0	0	0	0	776
10/4	127	245	6	8	0	0	0	386
25/4	299	884	17	15	0	0	0	1215
10/5	3783	3760	31	22	9	0	4	7609
25/5	4313	3909	42	28	8	4	7	8311
10/6	1865	2297	9	0	0	0	0	4171
25/6	0	0	0	0	0	0	0	0
10 & 25/7.	0	0	0	0	0	0	0	0
10 & 25/8	0	0	0	0	0	0	0	0
Total	14257	14651	167	102	17	4	11	29209

hemipterans (5 species). The most widespread are the hoverfly *Episyrphus balteatus* (De Geer, 1776), the green lacewing *Chrysoperla carnea* (Stephens, 1836), the ladybugs *Coccinella septempunctata* (Linné, 1758) and *Coccinella algerica (*Kovàr 1977)**, t**he gall midge Aphidoletes aphidimyza (Rondani, 1847), and a parasitic hymenopteran, *Lysiphlebus fabarum* (Marshall, 1896).

3.2.2 Richness, abundance, and dominance of the main aphidophages predators present in the citrus-growing environments surveyed

To calculate the indices of composition related to predators, we found it useful to limit ourselves to the most abundant and efficient species. In terms of richness

Table 5: List of aphidophages associated with aphids in the study environments

Class	Order	Family	Species	Status
Arachnida	Araneae	Araneidae	*Araneus diadematus* (Clerck,1757)	Predator
			Araneidae sp	Predator
Insecta	Mantodea	Mantidae	*Mantis religiosa* (Linné, 1758)	Predator
			Sphodromantis sp. (Stal, 1871)	Predator
			Iris oratoria (Linné, 1758)	Predator
	Dermaptera	Forficulidae	*Forficula auricularia* (Linné, 1758)	Predator
		Anisolabidae	*Anisolabis* sp. (Fieber, 1853)	Predator
	Hemiptera	Lygaeidae	*Lygaeus* sp. (Fabricius, 1794)	Predator
		Anthocoridae	*Anthocoris* sp. (Fallen, 1814)	Predator
			Orius sp. (Wolff, 1811)	Predator
			Cardiastethus sp. (Fieber, 1860)	Predator
		Geocoridae	*Geocoris* sp. (Fallén, 1814)	Predator
	Coleoptera	Carabidae	Carabidae sp	Predator
			Brachinus sp. (Weber, 1801)	Predator
			Chlaenius sp.1 (Bonelli, 1810)	Predator
			Harpalus attenuatus (Steph, 1828)	Predator
			Ophonus pubescens (Mull, 1776)	Predator
			Acinopus sp. (Dejean, 1821)	Predator
			Agonum sp. (Bonelli, 1810)	Predator
			Zabrus distinctus (Lucas, 1842)	Predator
		Staphylinidae	*Ocypus olens* (Muller,1764)	Predator
			Anthophagus sp. (Grav, 1802)	Predator
		Coccinellidae	*Coccinella septempunctata* (Linné, 1758)	Predator
			*Coccinella algerica (*Kovàr 1977)	Predator
			Scymnus sp. (Kugelann, 1794)	Predator
	Diptera	Syrphidae	*Episyrphis balteatus* (De Geer, 1776)	Predator
		Cecidomyiidae	*Aphidoletes aphidimyza* (Rondani, 1847)	Predator
	Neuroptera	Chrysopidae	Chrysoperla carnea (Stephens, 1836)	Predator
	Hymenoptera	Vespidae	*Vespula germanica* (Fabrice, 1793)	Predator
			Vespidae sp. (Latreille, 1802)	Predator
		Braconidae	*Aphidius colemani* (Viereck, 1912)	Parasitoid
			Lysiphlebus fabarum (Marshall, 1896)	Parasitoid
		Ichneumonidae	Ichneumonidae sp.1 (Latreille, 1802)	Parasitoid
			Ichneumonidae sp. 2	Parasitoid

Table 6: Richness, abundance, and dominance of the main predators collected in citrus orchards in the Chlef region

	Predators						
Settings	Hoverflies	Lacewings	Ladybugs	Midges	Bugs	Others	Total
Richness	1	1	3	1	5	19	30
Abundance	65	75	100	4	45	30	319
Frequency%	20.37	23.51	31.35	1.25	14.11	9.4	100
Constancy	regular	regular	regular	Accidental	Accessory		

and frequency, ladybugs are the most numerous with 100 individuals (31.35 %), followed by lacewings with 75 individuals (23.51 %), then hoverflies with 65 individuals (20.37 %), then bugs with 45 individuals (14.11 %), and finally gall midges with only 4 individuals, or 1.25 %. Other generalist predators that can have an impact on aphid control are also present, with a total of 30 individuals (9.4 %), distributed over 19 different species (Table 6).As for the monthly frequency of these auxiliaries, it appears that ladybugs and hoverflies appear first in March and disappear last at the end of October, with high numbers in April and May. As for lacewings, they only appear from the end of April and disappear late in mid-November. As for bugs, gall midges, and other predators, their presence is limited only to spring and a little less in summer (Table 7).

Table 7: Temporal evolution of the numbers of aphidophages during the prospection period

Date	Hoverflies	Lacewings	Ladybugs	Midges	Bugs	Others	Total
10/9	2	3	3	0	0	0	8
25/9	1	2	2	0	0	0	5
10/10	0	1	5	0	0	0	6
25/10	1	0	4	0	0	0	5
10/11	0	2	0	0	0	0	2
25/11	0	0	0	0	0	0	0
10 &25/12	0	0	0	0	0	0	0
10 & 25/1	0	0	0	0	0	0	0
10/2	0	0	0	0	0	0	0
25/2	0	0	0	0	0	0	0
10/3	2	0	0	0	0	0	2
25/3	4	0	8	1	0	0	13
10/4	8	0	10	2	11	0	31
25/4	7	11	12	1	10	7	48
10/5	8	15	9	0	7	5	44
25/5	10	12	8	0	7	5	42
10/6	5	6	7	0	5	7	30
25/6	6	8	12	0	4	2	32
10/7	4	5	7	0	1	3	20
25/7	3	4	4	0	0	1	12
10/8	2	2	5	0	0	0	9
25/8	3	3	4	0	0	0	10
Total	65	75	100	4	45	30	319

3.2.3 Diversity of aphidophages in the study environments

The diversity of aphidophage was translated by calculating the Simpson, Shannon-Wiever, and Equitability indices (Table 8).The values of these indices show that the highest diversity of aphidophage is observed at the end of April, with D = 0.59, H = 2.42, and E = 0.49. This diversity then regresses until it becomes zero in November, before increasing again from the beginning of March.

3.3 TEMPORAL DISTRIBUTION OF WINGLESS APHIDS AND THEIR NATURAL ENEMIES THROUGH AN AFC

For the study of the temporal evolution of the different species of aphids as well as their natural enemies, on the one hand, and the interactions that could exist between them, on the other hand, we carried out an AFC, from which we retained the results of the first two axes, which explain 85.72 % of variability. The positive side of axis 1 shows a correlation between syrphids, ladybugs, and lacewings, which are in turn correlated with *Myzus persicae* and the end of March. The second axis shows, on the positive side, a correlation between *Aphis spiraecola, Aphis fabae, Toxoptera citricida*, and *Aphis nerii,* which are in turn correlated with the March-April period. On the negative side of the same axis, the interaction of the aphids *Toxoptera aurantii* and *Aphis gossypii* with

Table 8: Values of diversity indices for aphidophagous populations in citrus orchards

Date	Simpson_1-L	Shannon_H	Evenness Index
10/9	0,35	1,07	0,19
25/9	0,31	1,05	0,17
10/10	0,33	1,01	0,11
25/10	0,30	0,9	0,1
10/11	0,21	0,7	0,08
25/11	0	0	0
10 &25/12	0	0	0
10 & 25/1	0	0	0
10/2	0	0	0
25/2	0	0	0
10/3	0,21	0,7	0,08
25/3	0,39	1,13	0,24
10/4	0,42	1,21	0,31
25/4	0,59	2,42	0, 49
10/5	0,54	2,38	0,41
25/5	0,52	2,37	0,4
10/6	0,43	1,24	0,35
25/6	0,45	1,25	0,36
10/7	0,41	1,21	0,31
25/7	0,37	1,12	0,23
10/8	0,35	1,09	0,2
25/8	0,36	1,11	0,22

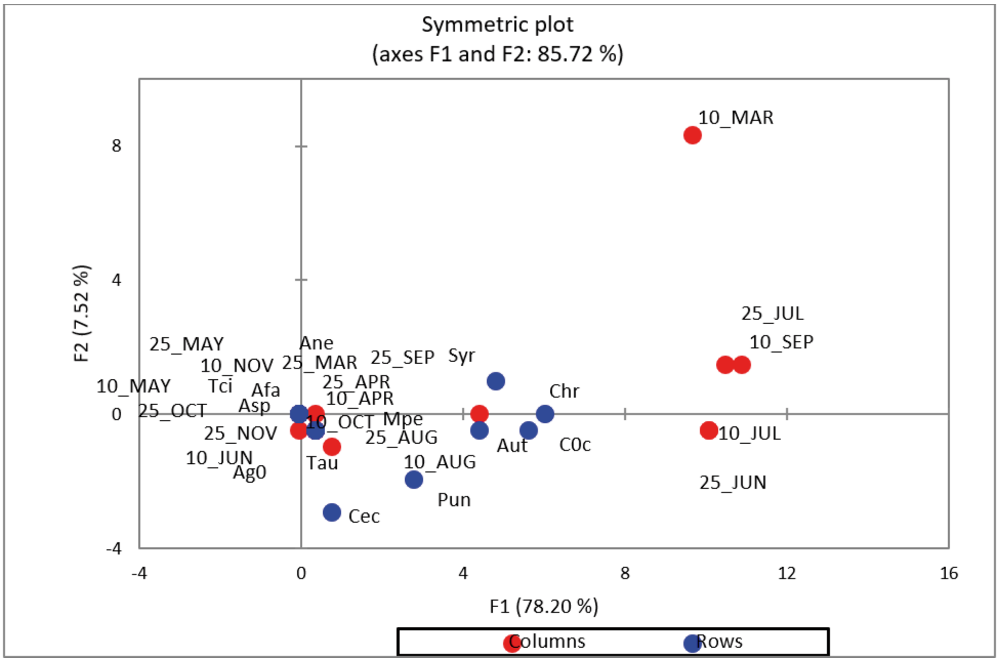

Figure 2: AFC applied to the populations of wingless aphids and their predators during the periods of prospections

gall midges and bugs during the period from August to November (Fig. 2) stands out.

4 DISCUSSION

In this study, the aphid fauna recorded is represented by seven species, the most widespread of which are *Aphis gossypii* and *Aphis spiraecola* , unlike *Toxoptera aurntii, Aphis fabae , Aphis nerii, Myzus persicae,* and *Toxoptera citricida* which were found in limited colonies. Aphids that are specialized in citrus are numerous. Barbagallo and Patti (1986) cited 17 species, but few of these species can have an economic impact on citrus production.

The abundance of *A. gossypii* and *A. spiraecola* reflects their cosmopolitanism and their polyphagy. The first is one of the main pests of citrus in many Mediterranean countries (Kavallieratos et al., 2002; Satar et al., 2014).In addition to these direct damages by feeding on tender shoots and flowers, it is responsible for the transmission of citrus tristeza virus. (Marroquín et al., 2004; Compra et al., 2000). As for the latter, it can, in addition to citrus, infest *Prunus* fruit trees in many Mediterranean countries (Ben Halima-Kamel and Ben-Hamouda, 2005). It is a key pet of *Citrus* x.*clementina* Tanaka in Spain, Algeria, France and Italy (Gomez-Marco, 2015). According to Mostefaoui et al. (2014), its abundance on the Clementine variety could be explained by a better tolerance to high levels of proline in the foliage.

In terms of species, predators are more numerous than parasitoids among natural enemies. However, the parasitism rate observed in aphid populations reflects the abundance of parasites in terms of numbers.

It is known that a parasitoid can only control a single host individual, unlike predators, of which a single individual can ingest a large number of pests. In fact, it has been proven that *Coccinella septempunctata* **c**an consume 469 to 725 individuals of *Myzus persicae* **i**n 17 to 19 days (Aroun, 2015), a syrphid larva can consume 400 to 700 aphids during its lifespan of 8 to 15 days (Deguine and Leclant, 1997) and a *Chrysoperla carnea* larva consumes 300 to 450 individuals **of** *Aphis craccivora* **(**Paulian, 1999).

The parasitoids encountered are four in number. It is worth noting that 29 species of aphid parasitoids are known in Algeria to date (Laamari et al., 2011).In our study areas, the most abundant parasitoid is *Lysiphlebus fabarum*, although Laamari et al. (2011) noted that *Aphidius matricariae* is the most frequent in aphid mummies in Algeria. *L. fabarum* was first reported in Algeria in 1993 in Mostaganem, (Guenaoui and Mahiout, 1993). It is associated with a wide range of host aphids worldwide (Stary, 1988). In Algeria, the sexual strain was found on 9 species of aphids associated with 18 species of host plants (Laamari et al., 2011). In Iran, 47 species of aphids have been reported as being parasitized by this species (Rakhshani et al., 2013).

Predators are mainly composed of insects, most of which are beetles. They even dominate the entomofauna associated with citrus fruits in the study region (Mohammedi et al., 2019).In terms of headcount; they are dominated by ladybugs, followed by lacewings and then hoverflies, although their abundance fluctuates according to the species' life cycle and the rate of prey presence. In Algeria, the fauna of ladybugs includes 48 species, of which 46 are biological control agents that can play a role in plant protection against certain pests (Sahraoui, 2017). However, 21 species that prey on citrus pests in a region of Algeria have been identified, of which Scymninae and Coccinellinae are quantitatively dominant (Sahraoui and Hemptinne, 2009).

Ladybugs are recognized as excellent predators of aphids at all stages of their life, they constitute the essential entomophagous group in the regulation of aphid populations. (Saharaoui et al., 2001).Their density increases with that of their prey (Sahraoui and Hemptinne, 2009). The presence of natural enemies is linked to climatic conditions, food availability (aphids) and species richness of the flora.

In addition to ladybugs, hoverflies are also known for their predation on aphids. The most widespread species is *Episyrphus balteatus,* but other species such as *Sphaerophoria scripta, Syritta pipiens* and *Eristalis tenax* are also abundant in a region of northeastern Algeria (Djellab et al., 2013). The larvae of hoverflies, especially those of *Episyrphus balteatus*, are also important predators for the control of aphids. Some predators show a preference for certain prey over others. Indeed, it has been shown that the effect of different prey species on the feeding capacity of *E. balteatus* larvae is higher on *Aphis gossypii and Myzus persicae* than on *A. craccivora* (Hong and Hung, 2010).

The diversity of aphidophages varies from season to season according to the life cycle of each species involved, as well as their reaction to variations in environmental conditions and prey availability. In fact, this diversity becomes important in the spring, but it regresses in the summer and autumn and becomes zero in the winter before appearing with low values at the beginning of spring. This translates to the life cycle of insects in general, which depends heavily on climatic conditions. Therefore, most insects die before the arrival of winter, and few of them hibernate in different shelters (Mohammedi, 2015). In addition, in temperate regions, adaptation to winter conditions is an important trait of the biological cycle that can influence their ecological and evolutionary success (Raymond et al, 2013). Some species of ladybugs, such as

C. algerica Kovár, 1977 **,** *Hippodamia variegata* (Goeze, 1777), and *P. subvillosus* Sturm, 1837, emerge from hibernation a little earlier and start laying eggs in early spring, and even earlier if climatic conditions become favorable. This is in contrast to the small-sized species **(***Scymnini, Platynaspini, Hyperaspini***)**, which begin their reproductive activities late and last until summer (Ben Halima-Kamel et al., 2011). Some authors think that the diversity of predator species has no effect on the strength of aphid suppression. Thus, for the biological control of aphids, conservation strategies that target the main predator species will be more effective than those that target the diversity of predators (Straub and Snider, 2006).In addition, the nature of prey can even influence the biological evolution of some predators, since it has been shown that females of *C. septempunctata* fed with *A. pisum* and *S. avenae* laid twice as many eggs as those fed with *A. fabae* and *A. craccivora* (Kalushkov and Hodek, 2004). Therefore, to succeed in biological control by conservation, it is necessary to know the effective entomopathogen and then act on the parameters that are favourable to it.

The AFC has identified affinities between aphid species and their potential predators. A large diversity of natural enemies coexist and share the same food (Sahraoui and Hemptinne, 2009; Sahraoui et al., 2015).In addition, it should be noted that the behaviour, abundance, and distribution of predators can be influenced by the physical characteristics of the habitat (Ben Halima Kamel et al, 2011), but also by the nature of the prey, regardless of its density. In fact, correlations between aphids and aphidophages, translating predation activities, are noted during the period from the end of March to November. The present analysis (AFC) also revealed a strong correlation between the ladybugs present, the hoverfly **(***E. balteatus***)** and the lacewing **(***Chrysoperla carnea***)** with *Myzus persicae*, unlike the bugs and the aphid midge **(***Aphidoletes aphidimyza***)** which showed a correlation with *Toxoptera aurantii* and *Aphis gossypii*. The choice of prey by the predator, in the case of aphid diversity, depends on both intrinsic and extrinsic factors. Thus, it has been shown that *C. septempunctata* showed higher predation efficiency for *Aphis craccivora, A. fabae* and *A. gossypii* than for other species (Sarker et al., 2019). On the other hand, *Acyrthosiphon pisum* Harris, 1766 and *Megoura viciae* Buckton, 1876 were more attractive to *E. balteatus***,** while *Aphis fabae* and all other aphids were less attractive. Similarly, the consumption of these two aphids increases the fecundity of the predator (Almohamad et al., 2007). It was also mentioned that the type of adjacent habitat and the identity of the predator affect the direction of predator movement. Thus, information on predator movement can be used to design the distribution of crops and natural habitats in agricultural landscapes that maximize pest control services (Samaranayake and Costamagna, 2019)**.** Even crop-associated plants are of great effect in the biological control of certain pests, as it has been shown that the sugar content of Mediterranean flowering plants, especially the trehalose content of pollen and nectar as a food resource for adult *Chrysoperla carnea*, has a positive impact on the fecundity and longevity of this insect predator (Gonzales et al., 2016).

The preservation and conservation of insect predators in general and aphidophages in particular allow for the biological and sustainable protection of agrosystems in general and citrus cultivation in particular. However, the success of this process requires the mastery of the interactions that occur between aphids, aphidophages, and the surrounding environment.

5 CONCLUSION

The aphid fauna recorded from the three citrus orchards surveyed is represented by seven species, the most widespread of which are *Aphis gossypii and Aphis spiraecola***.** The colonies of aphids are only present during the autumn and spring periods. These are associated with an aphidophages fauna consisting of 34 species, of which 30 are predatory and 4 are Parasitoid**.** However, the most widespread aphidophages are *Episyrphus balteatus***,** *Chrysoperla carnea, Coccinella septempunctata, Aphidoletes aphidimyza* (predators), and *Lysiphlebus fabarum* (parasitoid).

In terms of richness and frequency, ladybugs are the most numerous with 100 individuals (31.35 %), followed by lacewings with 75 individuals (23.51 %), then by hoverflies with 65 individuals (20.37 %), then by bugs with 45 individuals (14.11 %), and finally by gall midges with only 4 individuals, or 1.25 %. Other generalist predators that can have an impact on aphid control are also present, with a total of 30 individuals (9.4 %) distributed over 19 different species.

The highest diversity of aphidophages is noted towards the end of April with D = 0.59, H = 2.42, E = 0.49. This diversity gradually regresses until it becomes zero from November onwards, before manifesting itself again from the beginning of March.

The study revealed affinities between aphid species and their potential predators. Indeed, correlations between aphids and aphidophages, translating predation activities, were noted during the period from the end of March to November. The choice of prey by the predator, in the case of aphid diversity, depends on both intrinsic and extrinsic factors.

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