

Entomological survey of aphids natural enemies on two vegetable crops (*Vicia faba* and *Solanum tuberosum*) in the mountainous region of Kabylie (Iferhounène, Algeria)

Nabila Taleb,¹ Samia Ait Amar-Berras,^{1,2} Karima Benoufella-Kitous¹

¹Laboratory of Ecology, Biotechnology and Health, Department of Biology, Faculty of Biological and Agronomic Sciences, Mouloud Mammeri University of Tizi-Ouzou; ²Agronomy and Environment Research Laboratory, Institute of Life and Natural Sciences, Ahmed Ben Yahia El Wancharissi University of Tissemsilt, Algeria

Abstract

A survey of aphid natural enemies was carried out on two crops faba bean (*Vicia faba*) and potato (*Solanum tuberosum*) in the Iferhounène region (Tizi Ouzou, Algeria) between November 2022 and March 2023. A total of 9 parasitoid species and 4 aphid predator species were recorded. In faba bean fields, *Coccinella algerica* was the most abundant predator (33.89%), followed by the parasitoids *Binodoxys angelicae* (♀, 15.25%) and *Aphidius matricariae* (♀, 11.86%), whereas syrphid flies such as *Episyrphus balteatus* were scarce (1.69%). In potato crops, *Aphidius ervi* (♂) was the dominant parasitoid (20%), followed by *Praon volucre* (♂, 15%), *Binodoxys angelicae* (♀, 12.5%), and *Eupeodes corollae* (2.5%). This study represents one of the first contributions to the characterization of entomophagous natural enemies in mountain vegetable crops of Kabylie (Algeria). The collected data enhance our understanding of entomological interactions in these agroecosystems, and the observed diversity, particularly among Coccinellidae and parasitoid Hymenoptera, highlights the promising potential for developing locally adapted biological control strategies.

Key words: inventory; natural enemies; parasitoids; *Vicia faba*; *Solanum tuberosum*.

Correspondence to: Samia Ait Amar-Berras, Institute of Life and Natural Sciences. Agronomy and Environment Research Laboratory. Ahmed Ben Yahia El Wancharissi University of Tissemsilt. Bougara Road, Ben Hamouda, 38004/38000 Tissemsilt, Algeria.

Tel.: +213 69 343 063. E-mail: s.aitamer@univ-tissemsilt.dz

Introduction

Vicia faba (faba bean) and *Solanum tuberosum* (potato) hold a strategic position in vegetable cropping systems owing to their high nutritional and agronomic value, serving as major sources of protein and carbohydrates, as well as contributing to crop rotation diversification and soil fertility enhancement.^{1,2} However, the sustainability of their production is under significant threat from various pests, particularly aphids (Hemiptera: Aphididae), which comprise about 450 species associated with cultivated plants and cause considerable economic and phytosanitary damage.^{2-5,6} They exhibit a remarkable ability to adapt to a wide range of host plants and remain active throughout the entire crop growth cycle.^{7,8} Their sap-sucking feeding habit causes direct damage by depleting plant resources and inducing physiological stress, resulting in leaf deformation, reduced growth, and significant yield losses.^{8,9} Moreover, their role as vectors of phytopathogenic viruses gives them major epidemiological importance, particularly in susceptible plants.^{1,10,11}

To manage pests affecting these two important crops, various control strategies are employed, including chemical, cultural, and biological methods.¹² In Algeria, the use of insecticides remains the

most widespread approach;¹²⁻¹⁴ however, this approach has major drawbacks, including its harmful effects on non-target wildlife and the environment. In this context, biological control, based on the intervention of natural enemies of aphids, is a more environmentally friendly alternative.^{4,5,8} These biological agents play an essential role in regulating aphid populations, thereby reducing yield losses and dependence on chemical inputs.^{11,15,16}

The natural enemies of aphids belong to several entomological families and play a key role in regulating their populations.^{12,17,18} In a context where aphid infestations increasingly threaten the sustainability of vegetable production, exploring ecological control alternatives has become essential. In Algeria, several studies have investigated aphids and their natural enemies,^{7,8,13,17,18} particularly in northern regions where surveys have reported aphid species and their predators or parasitoids on major crops. For example, previous research documented potato aphids and their natural enemies in the Tizi-Ouzou area (Kabylie region).⁷ However, no study to date has explored aphid populations or their associated fauna in the Iferhounène mountains, located at over 1,100 m above sea level in the southeastern part of the Tizi-Ouzou province, a representative high-altitude Mediterranean agroecosystem. Therefore, the present work repre-

sents the first entomological survey conducted in this mountainous area, focusing on fava bean and potato crops.

Specifically, the objectives are to identify dominant species, assess their relative abundance by crop type, and evaluate their potential as biological control agents. This work provides key insights for developing integrated pest management strategies tailored to local ecological conditions, thereby promoting more sustainable agriculture in mountainous environments.

Materials and Methods

Study area

This study was carried out in the Iferhounène region, situated in the mountainous area of Kabylie, in the southeastern part of Tizi-Ouzou Province, northern Algeria (Figure 1). The region is characterized by rugged terrain and a high elevation of approximately 1,100 m above sea level, with geographical coordinates 36°32'02" N and 4°22'12" E. It has a Mediterranean mountain climate, marked by cold, snowy winters and mild summers, making it ecologically distinct from the coastal zones of Tizi-Ouzou. The area experiences frequent snowfall and no pesticide use, representing a typical mountainous agricultural ecosystem of Kabylie. These environmental characteristics offer an appropriate agroecological context for assessing the natural dynamics of insect populations in vegetable cropping systems.

The study was conducted during the 2022–2023 agricultural season, from November 2022 to March 2023, on two plots within a 1.9-hectare orchard. These plots were selected for their agronomic uniformity and accessibility for regular monitoring. The first plot, covering 243 m², was cultivated with fava beans, while the second plot, covering 240 m², was planted with potatoes. Both crops were grown following traditional local farming practices, without any chemical interventions (insecticides or other plant protection products), to

allow an objective assessment of the natural dynamics of insect populations. All cultural operations (soil preparation, sowing, irrigation, manual weeding, etc.) were carried out uniformly and monitored regularly, ensuring comparable experimental conditions between the two cropping systems.

Trapping with yellow traps

Each experimental plot was subdivided into nine homogeneous blocks to ensure spatial representativeness of the sampling. A yellow trap was installed at the center of each block (Figure 2). The yellow traps consisted of plastic trays (Ø:27 × h:10 cm) colored bright yellow to attract flying insects. Each tray was filled with water mixed with a few drops of odorless detergent to reduce surface tension, without any adhesive. Traps were positioned approximately 10 cm above the plant canopy using wooden supports. One trap was deployed per block and remained in place continuously throughout the sampling period. The water in the traps was renewed weekly during each collection to maintain trapping efficiency. Natural enemies were counted weekly. All insects captured in the yellow traps were carefully collected using a fine brush or entomological forceps, then transferred to Petri dishes (for predators) or to test tubes containing 70% ethanol (for parasitoids). Each Petri dish and test tube was labeled with the collection date and the corresponding host plant. To maintain trapping efficiency, the water in the yellow traps was renewed at each collection. The collected specimens were then transported to the laboratory for taxonomic identification.

Direct observations of natural enemies in the field

To assess the diversity and abundance of aphid natural enemies, one plant was randomly selected within each quadrat. Sampling was performed through direct visual inspection of different plant parts (leaves, stems, and flowers) to detect live aphidophagous predators. Specimens were collected manually at a rate of one plant per block

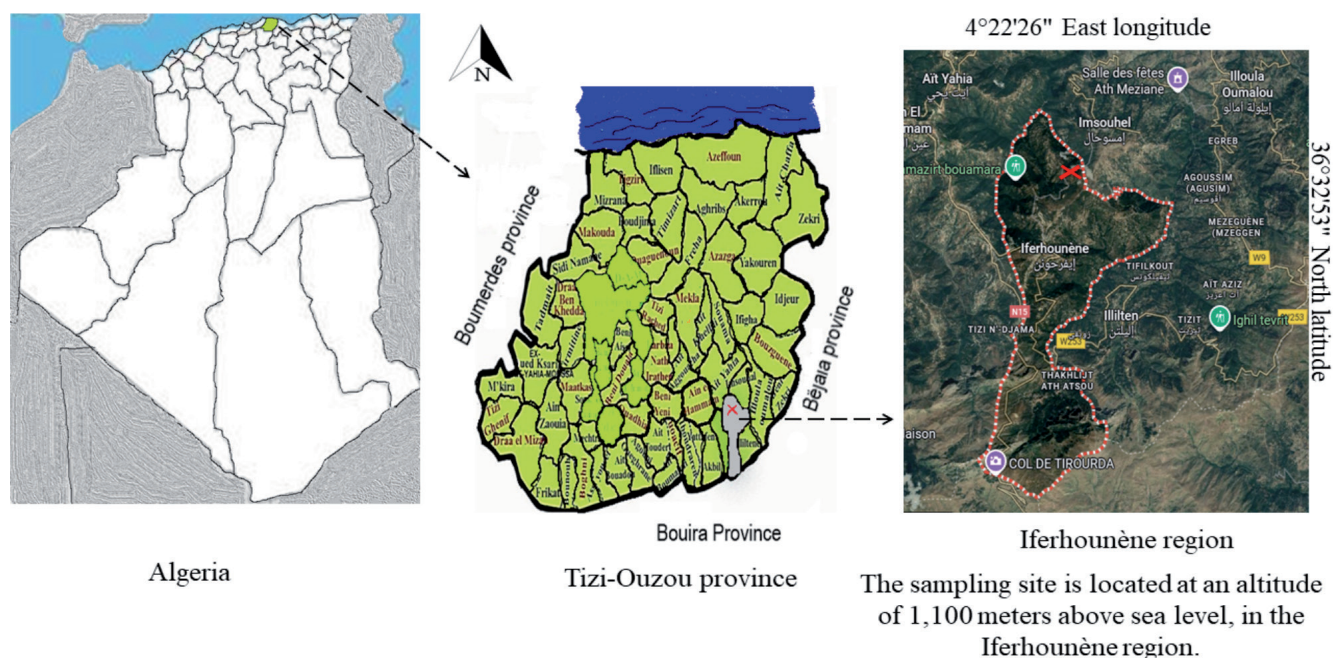


Figure 1. Geographic location of the sampling site in the Iferhounène region (Tizi-Ouzou Province, Algeria).

each week. This method allowed monitoring of the temporal dynamics of beneficial insect populations in relation to the observed crops.

Identification in the laboratory of collected insects

The collected insects were identified in the laboratory using several taxonomic keys for the main insect orders and families. Specimens, including hoverflies, ladybirds, and microhymenopterans, were sorted, counted, and identified to the species level under a binocular stereomicroscope (Motic SMZ-171, Motic Asia, Kowloon, Hong Kong) by Prof. Benoufella-Kitous Karima (Laboratory of Ecology, Biotechnology and Health, Mouloud Mammeri University of Tizi-Ouzou, Algeria) and Dr. Ait Amar-Berras Samia (Agronomy and Environment Research Laboratory, Ahmed Ben Yahia El Wancharissi University, Tissemsilt, Algeria).

Data analysis

In this study, both composition indices (percentage frequency) and structure indices (Shannon diversity index H' , and evenness index E) were calculated.

Diversity was assessed using the Shannon–Wiener index,¹⁹ while aphid species richness was analyzed by calculating the relative abundance of each species following the formula reported by Dajoz:²⁰

$$F(\%) = n_i \times 100/N$$

Where:

n_i : number of individuals of the species considered.

N : total number of individuals of all species combined.

The Shannon diversity index varies with the number of species present and the abundance of each.²¹ It is calculated using the following formula:

$$H' = - \sum q_i \log_2 q_i$$

Where:

H' : Shannon diversity index expressed in binary units.

q_i : Probability of occurrence of the species ($q_i = n_i/N$, where n_i is the number of species in the sample and the number of individuals, and N is the sum of n_i of all species combined).

$\log_2$: logarithm - base 2.

The equity index (E) considers the relationship between actual and theoretical maximum diversity,²² according to the following formula:

$$E = H' / H' \text{ max.}$$

Where:

H' : Shannon diversity index expressed in bits.

$H' \text{ max} = \log_2(S)$: maximum diversity index expressed in bits, where S is the total number of species.

A Chi-square test ($\chi^2 = 55.386$, $df = 25$, $p < 0.001$) was also performed to compare the distribution of aphid natural enemies between fava bean and potato crops. The analysis revealed a highly significant difference between the two host plants, as indicated by the very low p value (< 0.001). This result was further supported by Monte Carlo method ($p = 0.0001$).

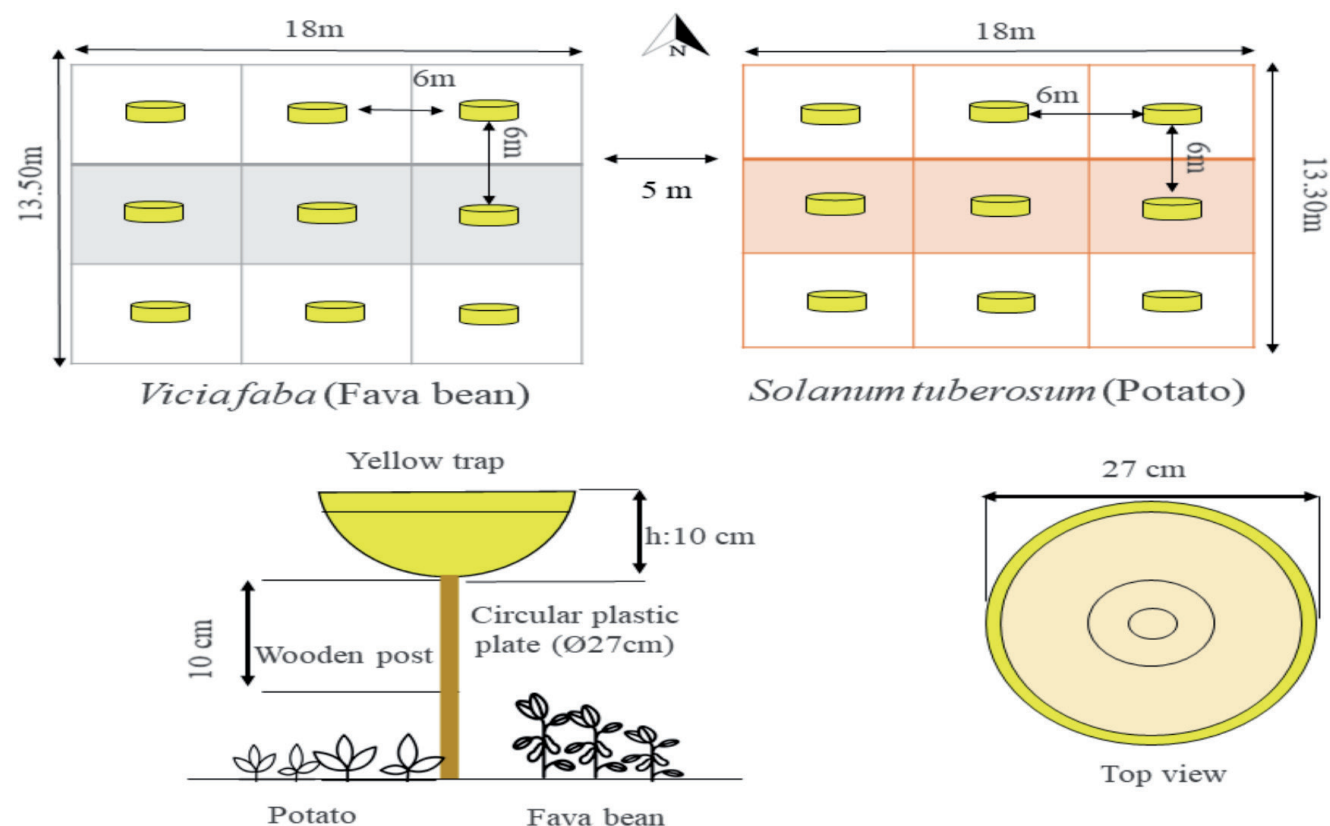


Figure 2. Block subdivision of fava bean and potato plots and technical design of the yellow water trap used for natural enemy monitoring.

Results

Taxonomic diversity of aphidophagous beneficial insects associated with fava bean and potato crops

Natural enemies are beneficial organisms that contribute to sustainable agriculture through their regulatory action on pest populations. The trapping program implemented in the two experimental plots allowed the identification of a diverse assemblage of aphidophagous beneficial insects. In total, 13 species were recorded, belonging to four subfamilies: Aphidiinae, Coccinellinae, Syrphinae, and Scymninae. Of these, 9 species were parasitoids (*Aphidius colemani*, *Aphidius ervi*, *Aphidius matricariae*, *Aphidius* sp., *Diaeretiella rapae*, *Ephedrus* sp., *Praon volucre*, *Binodoxys angelicae* and *Binodoxys* sp.) and four were predators (*Coccinella algerica*, *Scymnus pallipediformis*, *Episyrphus balteatus*, and *Eupeodes corollae*), representing seven tribes and nine distinct genera. The subfamily Aphidiinae was the most represented, encompassing four main tribes: Aphidiini, Praini, Trioxini, and Ephedrini (Table 1).

The inventory results revealed clear differences ($\chi^2=55.386$, $df=25$, $p < 0.001$) in the composition of auxiliary communities between the two crops, with some species shared between plots and others specific to one crop. In fava bean, seven genera *Aphidius*, *Diaeretiella*, *Praon*, *Binodoxys*, *Ephedrus*, *Coccinella*, and *Episyrphus* were recorded, distributed among three subfamilies

(Aphidiinae, Syrphinae, Coccinellinae) and six tribes (Aphidiini, Praini, Ephedrini, Trioxini, Coccinellini, and Syrphini). In potato, seven genera *Aphidius*, *Diaeretiella*, *Ephedrus*, *Praon*, *Binodoxys*, *Scymnus*, and *Eupeodes* were identified, belonging to three subfamilies (Aphidiinae, Syrphinae, Scymninae) and six tribes (Aphidiini, Praini, Ephedrini, Trioxini, Scymnini, and Syrphini).

A comparative analysis between crops showed seven species in common: *Aphidius ervi*, *Aphidius matricariae*, *Aphidius* sp., *Diaeretiella rapae*, *Ephedrus* sp., *Praon volucre*, and *Binodoxys angelicae*. Conversely, six species were exclusive to fava bean, namely *Aphidius colemani*, *Ephedrus* sp., *Binodoxys angelicae*, *Coccinella algerica*, and *Episyrphus balteatus*, while five species were exclusive to potato, including *Aphidius colemani*, *Praon volucre*, *Binodoxys* sp., *Scymnus pallipediformis*, and *Eupeodes corollae* (Table 1).

Diversity and relative abundance of all aphidiphagous auxiliary species in fava bean and potato crops

During the sampling period, a total of 99 natural enemies of aphids were recorded in the two experimental plots fava beans and potatoes through yellow traps and direct plant observations. The fava bean plot supported the highest abundance and diversity, with 59 individuals (59.6% of the total), compared to 40 individuals (40.4%) in the potato plot (Table 2).

Table 1. Diversity of aphidophagous beneficial insects recorded in fava bean (*Vicia faba*) and potato (*Solanum tuberosum*) crops in Iferrhounène (Tizi-Ouzou, Algeria).

Subfamilies	Tribe	Genus	Species	Sex/Stage	Crops	
					VF	ST
Aphidiinae	Aphidiini	<i>Aphidius</i>	<i>Aphidius colemani</i> (Viereck, 1912)	Female	-	+
				Male	+	-
			<i>Aphidius ervi</i> (Haliday, 1834)	Female	+	+
				Male	+	+
			<i>Aphidius matricariae</i> (Haliday, 1834)	Female	+	+
				Male	+	+
			<i>Aphidius</i> sp.	NID sex	+	+
				Male	+	-
		<i>Diaeretiella</i>	<i>Diaeretiella rapae</i> (McIntosh, 1855)	Female	+	+
				Male	+	+
			<i>Ephedrus</i> sp.	Female	+	+
				Male	+	-
	Praini	<i>Praon</i>	<i>Praon volucre</i> (Haliday, 1833)	Female	-	+
				Male	+	+
		<i>Binodoxys</i>	<i>Binodoxys angelicae</i> (Haliday, 1834)	Female	+	+
				Male	+	-
		<i>Ephedrus</i>	<i>Binodoxys</i> sp.	Female	-	+
			<i>Ephedrus</i> sp.	NID sex	+	-
Coccinellinae	Coccinellini	<i>Coccinella</i>		2-stage larva	+	-
				3-stage larva	+	-
			<i>Coccinella algerica</i> (Kovar, 1977)	Larva	+	-
				Adult	+	-
					+	-
Scymninae	Scymnini	<i>Scymnus</i>	<i>Scymnus pallipediformis</i> (Gunther, 1958)	Adult	-	+
Syrphinae	Syrphini	<i>Episyrphus</i>	<i>Episyrphus balteatus</i> (De Geer, 1776)	3-stage larva	+	-
		<i>Eupeodes</i>	<i>Eupeodes corollae</i> (Fabricius, 1974)	Female	-	+
				Male	-	+
4	6	9	14		20	16

VF, *Vicia faba* (fava bean); ST, *Solanum tuberosum* (potato); NID sex, Sex not identified.

Table 2. Diversity and relative abundance (Fi %) of aphidiphagous auxiliary species captured using yellow traps and direct observations in fava bean (*Vicia faba*) and potato (*Solanum tuberosum*) crops.

Crops/Species	Sex/Stage	<i>Vicia faba</i> (fava bean)		<i>Solanum tuberosum</i> (potato)	
		Ni	Fi (%)	Ni	Fi (%)
<i>Aphidius colemani</i> (Viereck, 1912)	Female	0	0	1	2.5
	Male	1	1.69	0	0
<i>Aphidius ervi</i> (Haliday, 1834)	Female	1	1.69	1	2.5
	Male	1	1.69	8	20
<i>Aphidius matricariae</i> (Haliday, 1834)	Female	7	11.86	1	2.5
	Male	2	3.38	3	7.5
<i>Aphidius</i> sp.	NID sex	1	1.69	4	10
	Male	1	1.69	0	0
<i>Binodoxys angelicae</i> (Haliday, 1834)	Female	9	15.25	5	12.5
	Male	2	3.38	0	0
<i>Binodoxys</i> sp.	Female	0	0	2	5
<i>Coccinella algerica</i> (Kovar, 1977)	2-stage larva	2	3.38	0	0
	3-stage larva	1	1.69	0	0
	Larva	2	3.38	0	0
	Adult	20	33.89	0	0
<i>Diaeretiella rapae</i> (McIntosh, 1855)	Female	2	3.38	2	5
	Male	2	3.38	1	2.5
<i>Ephedrus</i> sp.	Female	1	1.69	1	2.5
	Male	1	1.69	0	0
<i>Ephedrus</i> sp.	NID sex	1	1.69	0	0
<i>Episyrphus balteatus</i> (De Geer, 1776)	3-stage larva	1	1.69	0	0
<i>Eupeodes corollae</i> (Fabricius, 1974)	Female	0	0	1	2.5
	Male	0	0	1	2.5
<i>Praon volucre</i> (Haliday, 1834)	Female	0	0	2	5
	Male	1	1.69	6	15
<i>Scymnus pallipediformis</i> (Gunther, 1958)	Adult	0	0	1	2.5
Total		59	100	40	100

Ni, Number of individuals; Fi%, Relative abundances; NID sex, Sex not identified; Chi-square test ($\chi^2 = 55.386$, $df = 25$, $p < 0.001$).

In the fava bean crop, the predator *C. algerica* was the most abundant species, representing 33.89% of captures. It was followed by the parasitoids *B. angelicae* (♀, 15.25 %) and *A. matricariae* (♀, 11.86%). Other species were recorded in lower proportions, such as *A. colemani* (♂), *D. rapae*, and *B. angelicae* (♂) (each 3.38%), and *P. volucre*, *Ephedrus* sp., *A. ervi* and *E. balteatus* (larva L3), each with 1.69% (Table 2).

In the potato crop, the parasitoid *A. ervi* (♂) was dominant, with a relative abundance of 20%, followed by *P. volucre* (♂, 15%) and *B. angelicae* (♀, 12.5%). Other species included *Aphidius* sp. (10%) and *A. matricariae* (♂, 7.5%). Lower abundances were recorded for *Binodoxys* sp. (♀), *D. rapae* (♀), and *P. volucre* (♀) (each 5%). The least represented species, each with 2.5%, were *A. matricariae* (♀), *A. colemani* (♀), *B. angelicae* (♀), and the hoverfly *E. corollae* (♂ and ♀) (Table 2).

Evaluation of the biodiversity and community structure of beneficial organisms

In fava bean cultivation, the Shannon diversity index (H') reached 3.40 bits, with an evenness value of 0.79, indicating a relatively homogeneous distribution of individuals among the different aphidiphagous species. The theoretical maximum diversity (H'_{max}) was 4.39 bits, confirming a moderate yet well-balanced species diversity. In potato cultivation, diversity was slightly higher, with an H' value of 3.58 bits and an H'_{max} of 4.00 bits. Evenness reached 0.89, reflecting a high degree of uniformity in the distribution of individuals across aphidiphagous species. Overall, these results indicate a well-defined species composition and a stable ecological balance in both agroecosystems (Figure 3).

All the results presented in Tables 1 and 2 and in Figure 3 corre-

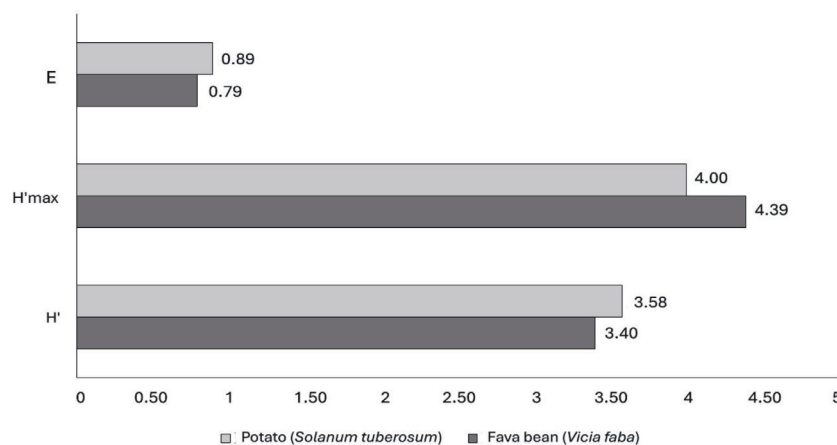


Figure 3. Shannon index values, maximum diversity and equitability computed for natural enemy species trapped in each cultivated plot.

spond to the identification of aphidophagous insects collected using traps and examined in the laboratory. However, no natural enemy species were directly observed on plants during field inspections, which may be due to low population densities or the timing of the surveys.

Discussion

According to the results obtained, the subfamily Aphidiinae (Hymenoptera: Braconidae) was predominant in both studied plots, comprising mainly four tribes: Aphidiini, Praini, Trioxini, and Ephedrini. This predominance underscores their essential role in the natural regulation of aphid populations. Globally, Aphidiinae encompass approximately 615 species, including 213 species in Europe, distributed among more than 50 genera classified into four tribes: Aclitini, Aphidiini, Ephedrini, and Praini.^{23,24} Among these, the genera *Aphidius*, *Praon*, *Diaeretiella*, and *Ephedrus* are frequently reported as effective biological control agents.^{23,25} These findings are in agreement with those of Akhtar *et al.*,³ in India, where Aphidiinae were also represented by the tribes Ephedrini, Praini, Aphidiini, and Trioxini, with a notably high species richness. In general, Aphidiinae are recognized as one of the most promising groups of solitary endoparasitoids of aphids, occurring in most habitats worldwide, particularly in temperate and subtropical zones.^{3,23} In Algeria, Hemidi and Laamari,¹³ reported a similar dominance of Aphidiinae in the oasis ecosystems of Ziban (Biskra region), with 17 species distributed across six genera (*Aphidius*, *Diaeretiella*, *Ephedrus*, *Lysiphlebus*, *Praon*, and *Binodoxys*), confirming their ecological importance in the natural control of aphid populations.

These results highlight the richness of the local entomophagous fauna and align with data previously documented at the national level. Hemidi and Laamari,¹³ reported 37 species of aphid parasitoids in Algeria in both natural and agricultural environments in the eastern part of the country, several of which were also recorded in our study (*A. colemani*, *A. ervi*, *A. matricariae*, *D. rapae*, *P. volucre*, *B. angelicae*). Comparable studies have been conducted in other Algerian regions. In Staoueli (northern Algeria), Slimani and Fekkoun,¹⁸ identified four predator species and eight parasitoid species in potato crops. In the northwest, Akrich *et al.*,¹⁷ also reported the occurrence of *D. rapae* and *A.*

matricariae. In Biskra, Hemidi *et al.*,²⁶ identified 11 parasitoid species associated with ornamental plants in public gardens, including *A. colemani*, *A. ervi*, *A. matricariae*, *D. rapae*, and *P. volucre*. Our observations are likewise consistent with findings from Tizi-Ouzou province, where Ait Amar *et al.*²⁷ reported 12 species of natural enemies in greenhouse crops, including *A. colemani*, *A. ervi*, and *D. rapae*. Moreover, in potato crops, Ait Amar *et al.*⁷ recorded 10 aphidophagous species, among which *A. ervi*, *D. rapae*, and *P. volucre* were the predominant parasitoids.

The marked differences in genera and species specific to each crop suggest that certain beneficial insects are closely associated with particular ecological conditions or trophic resources provided by fava beans or potatoes.^{18,26} The bean plot appeared to provide a more favorable habitat for a greater diversity of genera, particularly predators such as Coccinellidae and Syrphidae which may be linked to plant architecture, the density of aphid colonies, or microclimatic factors.²⁶ Conversely, the exclusive occurrence of the *Scymnus* and *Eupeodes* genera in the potato plot indicates a possible ecological adaptation to this crop.¹⁸ This affinity may be driven by several factors, including the specific composition of aphid colonies, oviposition preferences, or the particular nectar and pollen requirements of adults, which vary according to the flora associated with each crop.^{18,26} Moreover, the presence of species common to both plots, such as *A. ervi*, *A. matricariae*, and *D. rapae*, each represented by both sexes, likely reflects the role of generalist beneficial insects capable of colonizing diverse crops and adapting to variable environmental contexts.²⁵ The gender-specific distribution observed in certain parasitoid species such as *A. colemani* (males on fava beans, females on potatoes), *P. volucre* (both sexes on potatoes, only males on fava beans), and *B. angelicae* (both sexes on fava beans, only females on potatoes) may be linked to ecophysiological differences between fava beans and potatoes. These differences can influence both the composition of host aphid communities and the microhabitat characteristics available to parasitoids. In parasitoid Hymenoptera such as *A. colemani*, sex allocation is strongly modulated by host quality, particularly host size, mobility, and the physiological state of the host plant.^{28,29}

Recent studies,²⁹ indicate that the morphological and chemical characteristics specific to each crop can modulate female oviposition behavior, leading to distinct spatial distributions between males and females. In *A. colemani* females generally concentrate in

areas with a high density of suitable hosts for their offspring, as observed in potato fields. They are particularly attracted by volatiles emitted by aphid-infested plants, a response that is amplified when plants are infected with viruses such as Cucumber Mosaic Virus (CMV) or Potato Virus Y (PVY). These cues reinforce female orientation towards crops like potatoes, where, according to the literature, their principal host, *Myzus persicae*, is abundant.²⁹⁻³¹ In contrast, males tend to occupy areas where females emerge or are guided by other cues, including visual or tactile signals, which may explain their higher presence on fava beans.³⁰ Environmental factors, such as water stress, also influence emergence patterns: during drought, the proportion of males among parasitoids increases markedly, suggesting that sex allocation is shaped by both host quality and the physiological condition of the host plant.^{28,31} Overall, these observations underscore the combined influence of host plant traits, aphid populations, and environmental conditions in shaping the spatial and sexual structuring of aphid parasitoid communities, with potential implications for their population dynamics.

As part of this study, the inventory of aphid natural enemies revealed four predatory species: *Coccinella algerica* (observed at larval stages L1, L2, L3, and adult stage), *Scymnus pallipediformis*, *Episyrphus balteatus*, and *Eupeodes corollae* (Table 1). This diversity may be linked to the vertical and open architecture of the host plants, which facilitates predator access to prey, as well as to the high abundance of aphids that provides a rich food source for both larval and adult stages of many beneficial species²⁶. Similar findings have been reported in other Algerian regions. In Lakhdaria (Bouira), Gacem *et al.*³² recorded *C. algerica*, *E. balteatus*, and *A. colemani* in citrus orchards. In Tizi-Ouzou, Ait Amar *et al.*²⁷ documented *C. algerica*, *S. pallipediformis*, and *E. balteatus* among the predator fauna in greenhouse crops. In a previous study on potato crops from the same region, Ait Amar *et al.*⁷ identified ten aphidophagous species, including seven predators: *Anthocoris nemoralis*, *Chrysoperla carnea*, *Adonia variegata*, *C. algerica*, *S. pallipediformis*, *Malacocoris chlorizans*, and *E. balteatus*.

Our findings confirm the critical role of parasitoids in aphid population regulation, a role shaped by factors related to crop type, plant architecture, aphid species composition, climatic conditions (especially temperature and humidity), and interspecific interactions.²⁵ The richness of Hymenoptera recorded in our survey can be attributed to the complexity and heterogeneity of the local environment.²⁶ This diversity, often region-specific, underscores the need to tailor biological control strategies to local ecological contexts.¹³ The results clearly demonstrate that local environmental conditions and resource availability strongly influence the composition and specialization of both parasitoid and predator communities. Such insights highlight the importance of conserving and enhancing these natural enemies across Algerian agroecosystems, to maximize their contribution in integrated pest management programs.

Our findings align with those of Francis *et al.*,³³ who reported the predominance of ladybirds, particularly *C. algerica* (Kovar, 1977), on fava bean crops in Belgium. This species, observed in our study at various developmental stages (Table 2), is widely distributed in Algeria and recognized as an effective predator of more than 20 aphid species.³⁴ Its dominance has been repeatedly confirmed across different Algerian agroecosystems: 65.31% in Lakhdaria,³² 21.43% in the northwest of the country,¹⁷ and over 40% in greenhouse crops in Tizi-Ouzou.²⁷ *C. algerica* has also been observed at all developmental stages on potato.⁷ As a polyphagous predator, it plays a crucial role in natural aphid regulation, especially in habitats

with high floral diversity and structural richness, which enhance its persistence and hunting efficiency.³²

In the present study, the parasitoid *A. matricariae* (Haliday, 1834) was among the dominant species on fava beans, with a relative abundance of 11.86%. In Algeria, *A. matricariae* ranks among the most frequently encountered parasitoids, occurring at 3.57% frequency in the northwest.¹⁷ According to Chaouche and Laamari,²⁵ this species parasitizes up to 23 aphid species, and its diversity and abundance are strongly associated with ecosystem structural complexity and plant diversity, factors that promote stable parasitoid communities. Beyond Algeria, *A. matricariae* has been reported from the Kurdistan region of Iraq on wheat, sorghum, and watermelon.³⁵ It is a cosmopolitan species with demonstrated effectiveness in biological control programs against *M. persicae* and other aphids.²³ As an oligophagous parasitoid, it can attack more than 10 aphid species in varied habitats.²⁵ Native to the Palearctic region, its range extends across Europe, North Africa, the Middle East, the Americas, and India.^{3,26}

A. ervi and *P. volucre* emerged as the most dominant parasitoids on potato crops. Their presence was also documented by Ait Amar *et al.*²⁷, albeit with lower relative abundances (0.3% each) in their survey. In eastern Algeria, Laamari *et al.*⁵¹ showed that both *A. ervi* and *P. volucre* are generalist parasitoids, capable of parasitizing up to 13 aphid species, including *Macrosiphum euphorbiae*. *A. ervi*, in particular, is noted for its broad host range and high number of tri-trophic associations,¹³ while *P. volucre* demonstrates a marked preference for aphids of the tribe Macrosiphini, especially the genus *Uroleucon*.¹³ Although often considered generalists, both taxa exhibit oligophagous tendencies due to their affinity for a relatively narrow, yet ecologically diverse, set of host aphids.²⁵

The parasitoid *B. angelicae* (Haliday, 1834) was recorded in both studied crops, with relative abundances of 15.25% on fava bean and 12.5% on potato (Table 2). Its presence was also confirmed by Hemidi and Laamari¹³, who reported this species parasitizing *Aphis rumicis* on *Rumex* sp. and *Aphis punicae* on pomegranate (*Punica granatum*). These findings underline the ecological adaptability of *B. angelicae* to a range of host species and habitats, reinforcing its potential value as a biological control agent in diversified cropping systems.

Regarding hoverflies, *E. corollae* (male and female) was recorded for the first time in the Kabylie region, with a relative abundance of 2.5%, observed exclusively in potato crops. The occurrence of this species in Algeria has been documented previously: Haffaïressas *et al.*³⁷ reported it among the dominant syrphids in the Guelma district (northeastern Algeria), while Mebarkia *et al.*³⁸ confirmed its presence in semi-arid environments in Tébessa, where it was listed among 37 syrphid species in a systematic survey. The current observation expands the known distribution of *E. corollae* in Kabylie and contributes to the knowledge of the regional entomofauna by confirming the establishment of *E. corollae* in Kabylie. Its known efficiency as a predator of aphids, combined with its demonstrated ability to colonize diverse Algerian agroecosystems, highlights its potential as a valuable natural enemy for integrated pest management in crops subject to high aphid pressure.

In addition, the syrphid *E. balteatus* was recorded at the larval stage (L3), with a relative abundance of 1.69% (Table 2). This species is among the most extensively studied aphidophagous hoverflies in Europe and North Africa.³⁹ In Algeria, its occurrence has been confirmed in multiple regions: Gacem *et al.*³² reported it in a citrus orchard in Lakhdaria with a low relative abundance of 3.06 %, Akrih *et al.*¹⁷ documented it in the northwest of the country with

10.72%, and Ait-Amar *et al.*²⁷ observed it in greenhouse crops in Tizi-Ouzou at 10.1%. A separate study by Ait Amar *et al.*,⁷ in the same region recorded a markedly higher abundance of 27% in a potato plot. Such variations in abundance suggest that *E. balteatus* responds strongly to environmental conditions. Its larvae are voracious predators of aphids, while adults act as important pollinators,^{15,39} making it a dual-function beneficial species in agroecosystems. Moreover, its field presence appears closely associated with specific climatic factors, particularly elevated temperatures combined with optimal humidity, which promote rapid larval development and adult emergence.

Our results (Figure 3) are consistent with those of Saharaoui *et al.*,⁴⁰ who reported a very high Shannon diversity index in ladybird populations, ranging from 4.04 to 4.35 bits. They are also substantially higher than the values reported by Ait Amar *et al.*,⁷ where potato cultivation exhibited low diversity ($H' = 0.69$ bits; $E = 0.22$; $H'_{\max} = 3.01$ bits). This discrepancy suggests that the agroecological conditions or cultivation practices applied in our plots favor the establishment of a more functionally diverse community. Moreover, Francis *et al.*³³ emphasized that insect diversity is strongly influenced by the immediate surroundings of the field. Similarly, Mohammadi *et al.*,⁴¹ in their investigation of entomofaunal diversity across four agroecosystems in northwestern Algeria, demonstrated that agricultural practices exert a decisive influence on the abundance of beneficial insects. Their results showed that uncultivated fields exhibited significantly higher diversity indices ($H' = 4.15$ bits; $E = 0.89$) compared with cultivated fields (H' ranging from 1.68 to 2.87 bits; E from 0.41 to 0.72), thereby highlighting the substantial impact of farming activities on entomological diversity.

Although this study provides valuable insights into the composition and abundance of aphid natural enemies in high-altitude agricultural systems of Kabylie, the findings are limited to the specific ecological conditions of the Iferhounène area. Further investigations in other mountainous regions of northern Algeria are needed to confirm these trends and to better understand how altitude, microclimate, and vegetation diversity influence aphid–natural enemy interactions.

Conclusions

The survey conducted in the mountainous region of Iferhounène (Tizi Ouzou) revealed a notable entomological richness, with 13 species of beneficial insects identified in fava bean (*Vicia faba*) and potato (*Solanum tuberosum*) crops. These findings demonstrate that mountain crops harbor a valuable diversity of natural enemies. This biodiversity could be exploited in biological control strategies to sustainably reduce aphid infestations while minimizing environmental impact.

Further research is needed to understand better the behavior, population dynamics, and field efficacy of these beneficial organisms. In the future, their integration into biological control strategies could contribute to the sustainable improvement of crop protection in mountainous agroecosystems.

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