JEE Journal of Ecological Engineering

Journal of Ecological Engineering 2023, 24(4), 99–109
https://doi.org/10.12911/22998993/159397
ISSN 2299–8993, License CC-BY 4.0

Received: 2022.12.28
Accepted: 2023.02.07
Published: 2023.02.20

Diversity of Aphids Associated with Field and under Greenhouse Crops (Wheat, Barley and Chili Pepper) across the Dryland Climate in Algeria

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ABSTRACT

The aim of this study was to investigate the diversity of aphids associated with the field and under greenhouse crops in an arid climate in southeastern Algeria (Biskra province). Using yellow basins for the insects sampling, a total of 6683 specimens of aphids were collected and identified into 33 species, five (05) subfamilies: *Aphidinae*, *Pemphiginae*, *Chaitophorinae*, *Pterocommatinae*, and *Greenideinae*; and six tribes: *Aphidini, Macrosiphin, Pemphigini, Panaphidini, Chaitophorini* and *Greenideini*, and 22 genera. The *Macrosiphini* tribe is quantitatively most dominant with 20 species (61%) of the inventoried aphid population, followed by the aphidini which groups together 9 species representing 27% of the aphids inventoried. The other tribes are less represented, including one species for each tribe (12% in total). *Aphis gossypii* was the predominant species 29.67% of the inventoried species, followed by *Rhopalosiphum maidis* (15.22%) and *Rhopalosiphum padi* (15.07%). In terms of total wealth (S), there was a strong and positive correlation between the diversity of aphids and crops ($R^2 = 0.73$), and also a significant relationship ($df = 15$, $Pr > F = 0.024$). Shannon's index spatial interpolation indicates a higher diversity on agricultural lands in the study area. Shannon's diversity and evenness index values were greater in pepper under greenhouse in Dhibia station (H′ = 2.01, E = 0.84) compared to barley and wheat, in El Haouch and Saada, respectively (H′ = 1.18, E = 0.30 and H' = 1.45, E = 0.21).

Keywords: aphid, diversity, crops, Biskra.

INTRODUCTION

Aphids are a very common group of insects around the world. There count currently 4700 species, [Delorme, 1997; Hulle et al., 1998] and 250 species are pests [Fraval, 2006]. Aphids are one of the most harmful insect groups to cultivated plants. The damages are caused either by toxicosis or by weakening the host, and are very serious due to aphids' rapid reproduction.

Morver, aphids are the main vectors of plant viruses [Fiebig and Poehling, 1998] and they can also develop resistance to insecticides [Bonnemain and Chollet, 2003]. According to van Emden and Harrington [2009], direct aphid damage to cereals includes stem stunting, yellowing and premature death of leaves, as well as reduction in grain size.

Aphids are among the most common pests threatening crops in Algeria, which has led many researchers to conduct studies on different type of crops in various regions in order to inventory these pests and recognize their way of life and their bio-ecological status [Aid, 2004; Laamari, 2004; Timoussarh, 2006; Benabba and Bengouga, 2007 ; Boujite, 2007; Merouani, 2009; Boughida, 2010 ; Dif, 2010; Assabah, 2011; Kellil, 2019].

Biskra region, in the south-west of Algeria is characterized by a dry climate, and an important agricultural activity; however, very few studies were carried out on the aphid associated with the different agrosystems in the region. Therefore, due to lack of data, this study aimed to make a preliminary inventory and assess the diversity and abundance of aphids associated with two types of cereals (wheat and barley) and pepper in greenhouses in several local areas. It also seemed necessary to identify the harmful species that can congregate and cause heavy yield losses.

MATERIALS AND METHODS

Study area

Biskra is situated in the southeast of Algeria at 34° 55' 37.2", 34° 45' 19.2" North, and 5° 47' 56.4" to 5° 37' 21.6" East, characterized by an arid climate with large seasonal variations; with hot summer (minimum temperature 17 °C in December, maximum temperature 41.76 °C in July, and Emberger's index Q2 = 11.3). Precipitation is low and irregular (maximum 20.33 mm in January) with an intense solar irradiance (between 221.4 hours in December and 356.7 hours in July), and a high evaporation (minimum average is 25.06% in July and the maximum average is in December).

The study was carried out in six localities in the province of Biskra (Fig. 1) on two municipalities: El Outaya and Sidi Okba.

Sampling methods and data collection

The study was carried out during two successive agricultural seasons (2014/2015 and 2015/2016) from January to May. Samples were taken from two plots of durum wheat, two of barley, and two others from greenhouse vegetable crops (chili pepper) located in six different sampling points: Lahzima, Dhamrania, Tangour, Dibia, Saada, and El Haouch.

For the experiment, yellow basins filled to two-thirds of their height with soapy water were placed. According to Mignon et al., [2003], the yellow basin technique remains the most frequently used model in the faunistic entomology of agricultural environments; their uses give very satisfactory results and lends itself to large-scale sampling.

For cereals, a total of 5 yellow basins were installed at each plot at a minimum distance of 50 m from the edges of the plots in order to avoid the border effect.

For greenhouse vegetable crops, 6 yellow basins were placed, 2 basins inside the plastic shelter, and 4 at its periphery. The placed basins were collected weekly throughout the period of the

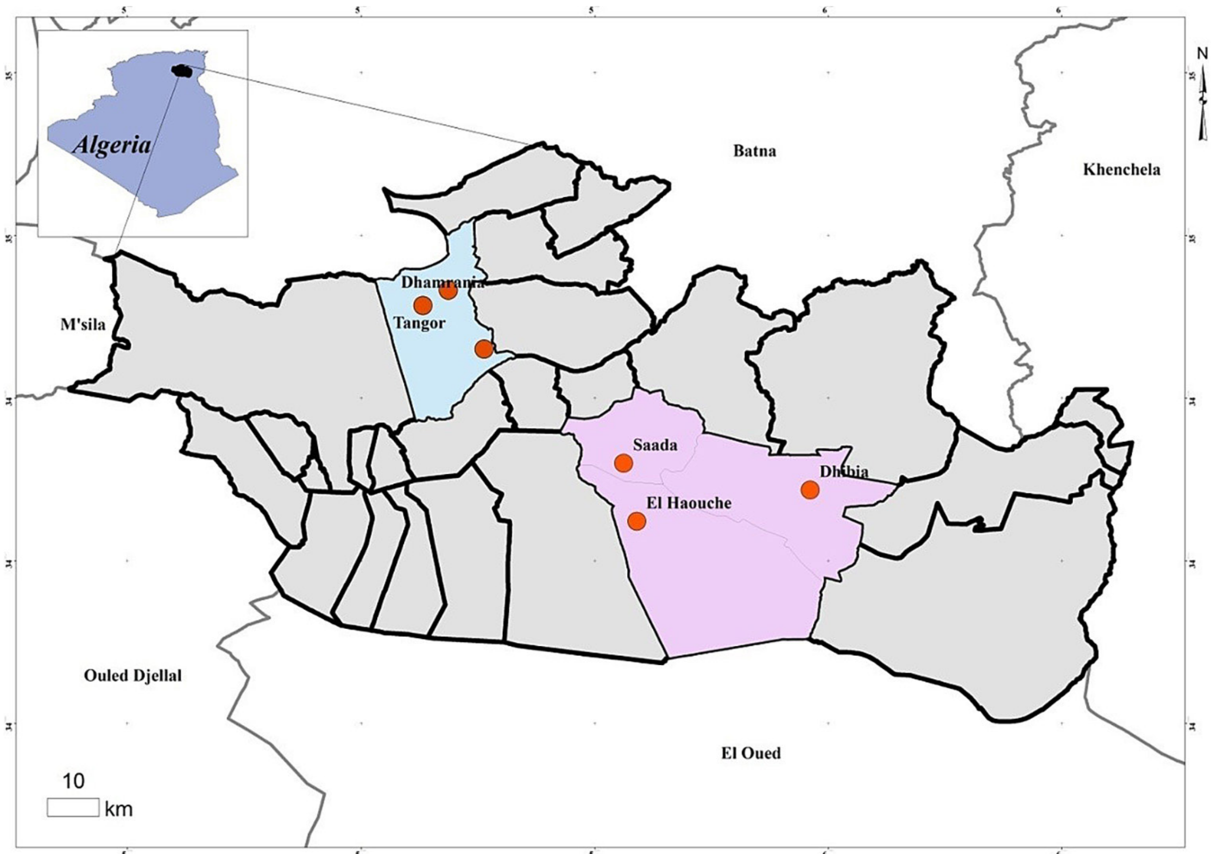

Figure 1. Geographical location of the study area

experiment. The specimens caught in the yellow traps are collected with a fine pin and kept in test tubes filled with 70% ethanol with a label indicating the place, date of collection, and the host plant (Durum wheat, barley or chili pepper). In the laboratory, the collected specimens were counted, and identified, using specialized identification keys [Stroyan, 1961; Jacky and Bouchery, 1982; Autrique and Ntahimpera, 1994; Remaudière et al., 1985; Leclant, 1999; Blackman and Eastop, 2000, 2006], according to Leclant [1978] the determination of aphids was based on relatively precise morphological characters as wingless and winged forms.

Data analysis – diversity parameters

The diversity of *Aphidofona* in each station was evaluated using different ecological indices:

1. the sampling quality is represented by the ratio a/N where (a) is the number of species seen only once; and (N) is the number of samples [Blondel, 1979]. It enables to identify the sectors for which the faunistic information is adequate [Lobo et al., 1997];
2. total wealth or species richness (S) it is the total number of species inventoried [Blondel, 1979; Ramade, 1984];
3. average wealth (Sm) according to Ramade [1984], (Sm) is the average number of species observed at each survey obtained by the following formula

$$Sm = \Sigma S/N \quad (1)$$

4. the N/S ratio;
5. the relative abundance (RA) of each species is the percentage of the number of individuals of a species ni on the total number N in each station

$$RA = ni \times \left(\frac{100}{N}\right) \quad (2)$$

6. Shannon diversity index (Blondel, 1973)

$$(H' = log2 - \Sigma pi) \quad (3)$$

where: H – diversity index expressed in bits;
Qi – the relative frequency of abundance of species i.
Shannon values vary between 0 and log2 S.

7. evenness E

$$E = H/Hmax \quad (4)$$

where: $Hmax$ = log2S (Magurran 2004);

8. simpson reciprocal index,

$$SRI = \left(\frac{1}{D}\right) \quad (5)$$

where: D = $\Sigma(ni(ni\text{-}1)/N(N\text{-}1))$;

9. The SRI/S ratio, which varies between 0 and 1.

Data analysis – geospatial and statistical analysis

Geospatial analyses assessed the spatial distribution of aphids' biodiversity in the study area of two ecological indices (Total richness S and Shannon diversity index H), using spatial interpolation of via simple Kriging due to its preference for intuition and wide use.

For statistical analysis, Shapiro–Wilk test was applied to verify the normality of the abundance data; then, the diversity and frequency of aphids at different localities were compared using the non-parametric Kruskal-Wallis test ($\chi 2$).

The relationships between aphid diversity parameters were verified using Pearson correlation tests for each station and for the whole region.

The plotting of the correlation matrices was done using the corrplot package in R. The influence of collection date on aphids' distribution pattern between stations was explored using principal component analysis (PCA) with the FactoMineR and Factoshiny packages in R. Statistical analyses were carried out in R version 4.1.0 (R Core Team 2022) and Microsoft Excel 2016 (Microsoft, Spring Valley, CA, USA).

RESULTS

Taxonomic list and abundances of aphids' species

In a total of 6683 specimens of aphid collected, 33 species were identified (Table 1) belonging to five (05) subfamilies, namely the *Aphidinae*, *Pemphiginae*, *Chaitophorinae*, *Pterocommatinae*, and *Greenideinae*; six tribes which are the *Aphidini*, *Macrosiphin*, *Pemphigini*, *Panaphidini*, *Chaitophorini* and *Greenideini*, and 22 genera. The *Macrosiphini* tribe is quantitatively the most dominant with 20 species (or 61% of the aphid population inventoried). It is followed by the *aphidini* which group together 9 species representing 27% of the aphids inventoried. The other tribes are less represented, they include one species for each tribe (12% in total) (Figure 2).

Table 1. Systematic list, the number of individuals and relative abundance of aphids recorded in field and protected crops (barely, wheat and chili pepper under greenhouse) in the Biskra region of southeastern Algeria

S/ familles	Tribu	Crops	Chili pepper		Barely		Wheat		Total	RA (%)
		Espèces	Dhibia	Lahzima	Tangour	El haouche	Saada	Dhamrania		
Aphidinae	Aphidini	*Aphis fabae* Scopoli, 1763	119	15	12	10	10	20	186	2.78
		Aphis gossypii Glover, 1877	417	1420	46	34	47	20	1984	29.69
		Aphis nerii Boyer de Fonscolombe, 1841	40	47	-	-	-	-	87	1.30
		Aphis craccivora Koch, 1854	42	50	-	-	-	-	92	1.38
		Aphis citricola Leclant & Remaudière, 1972	0	3	-	-	-	-	3	0.04
		Brachycaudus helychrysi Kaltembacher, 1843	129	83	10	-	-	2	224	3.35
		Brachycaudus cardui Linné, 1758	31	26	-	-	-	-	57	0.85
		Schizaphis graminum	-		5			3	8	0.12
		Hyalopterus pruni (Geoffroy, 1762)	-	7	-	-	-	-	7	0.10
	Macrosiphini	*Aulacorthum solani* Kaltenbacher, 1843	55	15	1			7	78	1.17
		Acyrthosiphon pisum Harris, 1776	0	46	0	12	5	-	63	0.94
		Brevicoryne brassicae Linné, 1758	66	384	-	-	-	-	450	6.73
		Rhopalosiphum maidis Fitch, 1856	490	124	101	82	133	88	1018	15.23
		Rhopalosiphum insertum (Walker, 1849)	-	12	-	-	-	-	12	0.18
		Hyperomyzus lactucae Linné, 1758	248	141	6	-	-	4	399	5.97
		Macrosiphum euphorbiae Thomas, 1878	145	52	12	-	-	6	215	3.22
		Macrosiphum rosae (Linnaeus, 1758)		136	-	-	-	-	136	2.04
		Metopolophium dirhodum (Walker, 1849)	50	18	25	-	-	-	117	1.75
		Rhopalosiphum padi Linné, 1758	689	61	66	68	69	24	1008	15.08
		Myzus persicae Sulzer, 1776	26	172	22	17	12	55	262	3.92
		Sitobion avenae Fabricius, 1775	67	-	58	-	11	13	156	2.33
		Sitobion fragariae	-		10	-	-	20	27	0.40
		Cavariella aegopodii (Scopoli, 1763)	-	10		-	-	17	10	0.15
		Megoura vicia Buckton, 1876	-		4	-	-	-	5	0.07
		Capitophorus elaeagni (Del Guercio, 1894)	-	29	-	-	-	1	29	0.43
		Chaitophorus sp Koch, 1854	5	-	-	-	-	-	5	0.07
		Hyadaphis foeniculi (Passerini, 1806)	-	6	-	-	-	-	6	0.09
		Hyadaphis coriandri (Das, 1918)	-	14	-	-	-	-	14	0.21
Pemphiginae	Pemphigini	*Pemphigus sp.*	-		3	-	-	-	4	0.06
Pterocommatinae	Panaphidini	*Myzocallis (Myzocallis) castanicola* Baker 1917	9	5	-	-	-	1	14	0.21
Chaitophorinae	Chaitophorini	*Sipha (Rungsia) maydis* Passerini, 1860	-	5	-	-	-	-	5	0.07
Greenideinae	Greenideini	*Greenidea ficicola Takahashi, 1921*	-	-	-	2		-	2	0.03

Note: RA (%) – relative abundance.

Relative frequency

Overall, *Aphis gossypii* was the aphid species with high capture frequency (29.67%), *Rhopalosiphum maidis* (15.22%), and *Rhopalosiphum padi* (15.07%), followed by the species of *Brevicoryne brassicae* and *Hyperomyzus lactuacae* which are classified in fourth and fifth position with respective values of relative frequency equal to 6.73% and 5.97%. The other species are classified as sporadic species (accidental, rare, or very rare) with a relative abundance < 3% (Figure 2).

The labeled individuals are those with the higher contribution.

There were highly significant relationships between aphids' abundances and the three crops ($\chi 2$ = 60.82, *df* = 14, *P* = 3.10). In terms of total wealth, there was a strong and positive correlation between the diversity of aphids and crops (R^2 = 0.73). With also significant relationships (*df* = 15, *P* = 2.91, *Pr* > *F* = 0.024).

Ascending Hierarchical Classification made on individuals reveals 3 clusters (Figure 3).

Cluster 1 is made of individuals such as *A. citricola*, *B. brassicae*, *Chaitophorus* sp, *H. lactucae*, *M. persicae,* and *S. avenae*, this group is characterized by low values in February, January, March, and April in El Haouche, Dhibia and Saada stations. As for crops, the lowest values were recorded for these species in both barley and chili pepper.

Cluster 2 is made of species such as *R. maidis* and *R. padi*. This group is characterized by high values in January, February, and March in both wheat and barley

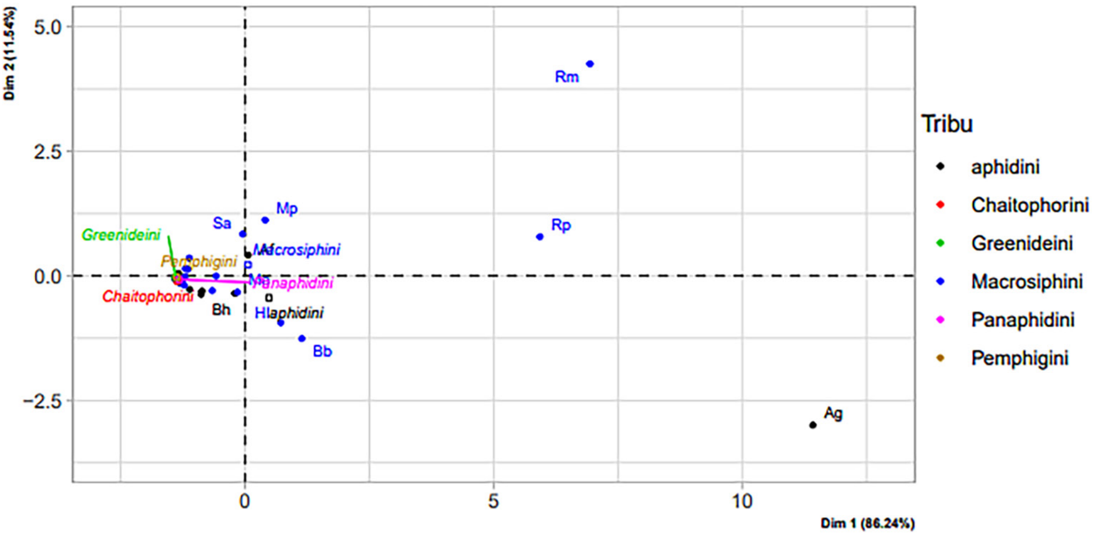

Figure 2. Plot of the Individuals factor map (Principal Components Analysis PCA)

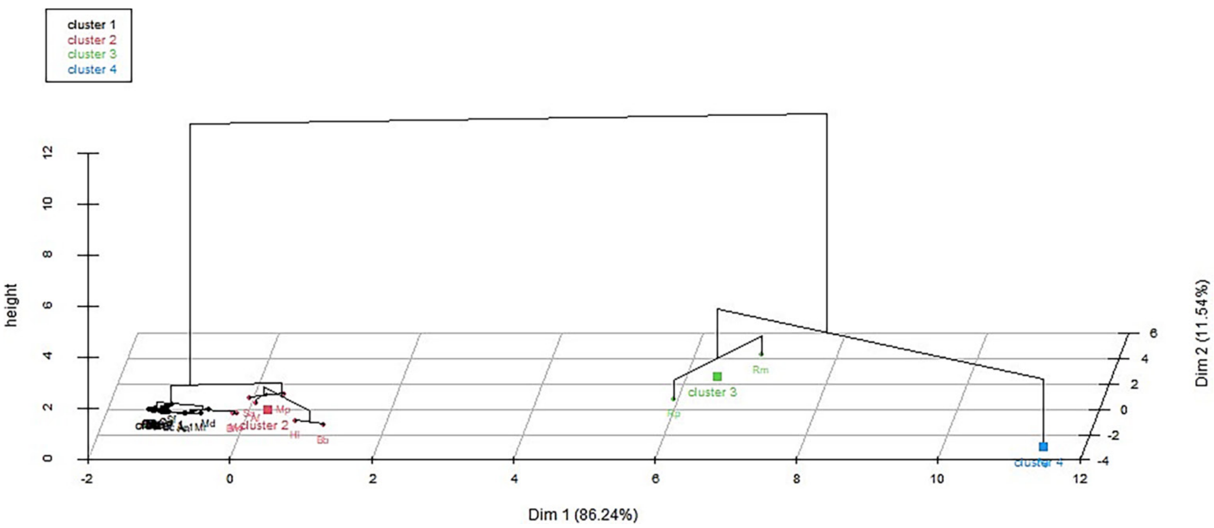

Figure 3. Ascending hierarchical classification of the individuals

Cluster 3 is made of individuals such as *Aphis gossypii*. This group is characterized by high values on chili pepper grown in greenhouse throughout the study period.

Variation of aphids' diversity parameters

The value of sampling quality in relation to the species trapped in the study sites oscillates between 0.08 in the Saada station and 0.17 in Lahzima (Table 2). These values are less than 1; thus, this sampling can be qualified as good. Therefore, the species observed only once in the study sites are classified as accidental species: (*Aulacorthum solani* and *Greenidea ficicola* (El Haouche), *Aphis citricola* (Lahzima), *Capitophorus sp* and *Lypaphis erysimi* (Saada), *Brachycaudus helichrysi* and *Pemphigus sp* in Dhamrania. In fact, these species are dependent on the spontaneous flora and / or forest trees found in the vicinity of the study sites.

The diversity parameters recorded in chili pepper grown under greenhouse were higher than

Table 2. The sampling quality test results

Test	Tangour	Saada	Dhamrania	El Houche	Lahzima	Dhibia
N	13	12	13	9	25	19
a	2	1	2	1	4	2
a/N	0.15	0.08	0.15	0.11	0.17	0.10

Note: a: Number of species seen only once; N: Number of readings; a / N: Sampling quality.

Table 3. Variation of diversity indices of aphids sampled in field and under greenhouse crops (wheat, barley and chili pepper) across the dryland in Algeria

		Region of study						
Diversity parameters	Input data	Dhamrania	Tangour	Lahzima	Dhibia	El Haouch	Saada	Overall
Number of individuals (*N*)	Sample based	55.2 ± 63.79	76.2 ± 93.36	45 ± 27.38	490.6 ± 351.49	45 ± 27.38	63 ± 60.78	198.16 ± 272.74
	Samples pooled	276	381	225	2453	225	315	6143
Species richness (*S*)	Sample based	6.6 ± 5.02	8.4 ± 4.97	5.4 ± 1.34	11.2 ± 3.49	5.4 ± 1.34	4.6 ± 2.88	8 ± 4.58
	Samples pooled	15	15	7	16	7	7	31
Ratio N/S	Sample based	18.4 ± 4.25	5.08 ± 6.22	6.42 ± 3.91	30.66 ± 21.96	6.42 ± 3.91	9 ± 8.68	6.39 ± 8.79
	Samples pooled	3.68	25.4	32.14	153.31	32.14	45	198.16
Shannon diversity index (H')	Sample based	2.72 ± 2.33	1.60 ± 0.66	1.38 ± 0.18	1.86 ± 0.31	1.38 ± 0.18	1.03 ± 0.68	1.44 ± 0.66
	Samples pooled	2.18	2.17	1.54	2.15	1.54	1.54	2.3
H'max	Sample based	3.9 ± 2.33	3.07 ± 2.31	2.43 ± 0.42	3.84 ± 1.80	2.43 ± 0.42	2.20 ± 1.52	3 ± 2.19
	Samples pooled	2.72	3.9	2.8	4	2.8	2.8	4.95
Evenness (E)	Sample based	0.76 ± 0.15	0.74 ± 0.13	0.76 ± 0.10	0.60 ± 0.08	0.76 ± 0.10	0.80 ± 0.17	0.70 ± 0.16
	Samples pooled	0.59	0.58	0.67	0.54	0.67	0.67	0.32
Simpson's reciprocal index (SRI)	Sample based	0.53 ± 0.38	0.71 ± 0.17	0.69 ± 0.05	0.79 ± 0.05	0.69 ± 0.05	0.53 ± 0.31	0.64 ± 0.25
	Samples pooled	0.84	0.85	0.74	0.84	0.74	0.73	0.84
Ratio SRI/S	Sample based	0.03 ± 0.02	0.04 ± 0.01	0.09 ± 0.007	0.04 ± 0.003	0.09 ±0.007	0.07 ± 0.04	0.02 ± 0.008
	Samples pooled	0.05	0.05	0.1	0.05	0.1	0.1	0.02

those of cereals (barley and wheat). The highest total wealth (S) value was recorded in the chili pepper under greenhouses in Lahzima and Dhibia (25 species in Lahzima and 18 others in Dhibia with a respective average richness of 3.84 and 4.75 species per sit) than on cereals (for wheat, 15 species in the Dhamrania station and 8 species at Saada station with a respective average richness of 2.27 and 1.8 species per sit, and for barley. A richness of 14 species was recorded in Tangour station with an average of 2.83 and 7 species in El Houche with an average of 1.33).

Normality tests revealed that species richness varied significantly between the three cultures ($\chi2 = 3.60$, $P = 0.335$, $R^2 = 0.71$). In parallel, the number of captured individuals was significantly different ($\chi2 = 3.429$, $P = 0.340$, $R^2 = 0.99$) between study sites. Shannon›s diversity and evenness index values were greater in the pepper grown under greenhouse in Dhibia station

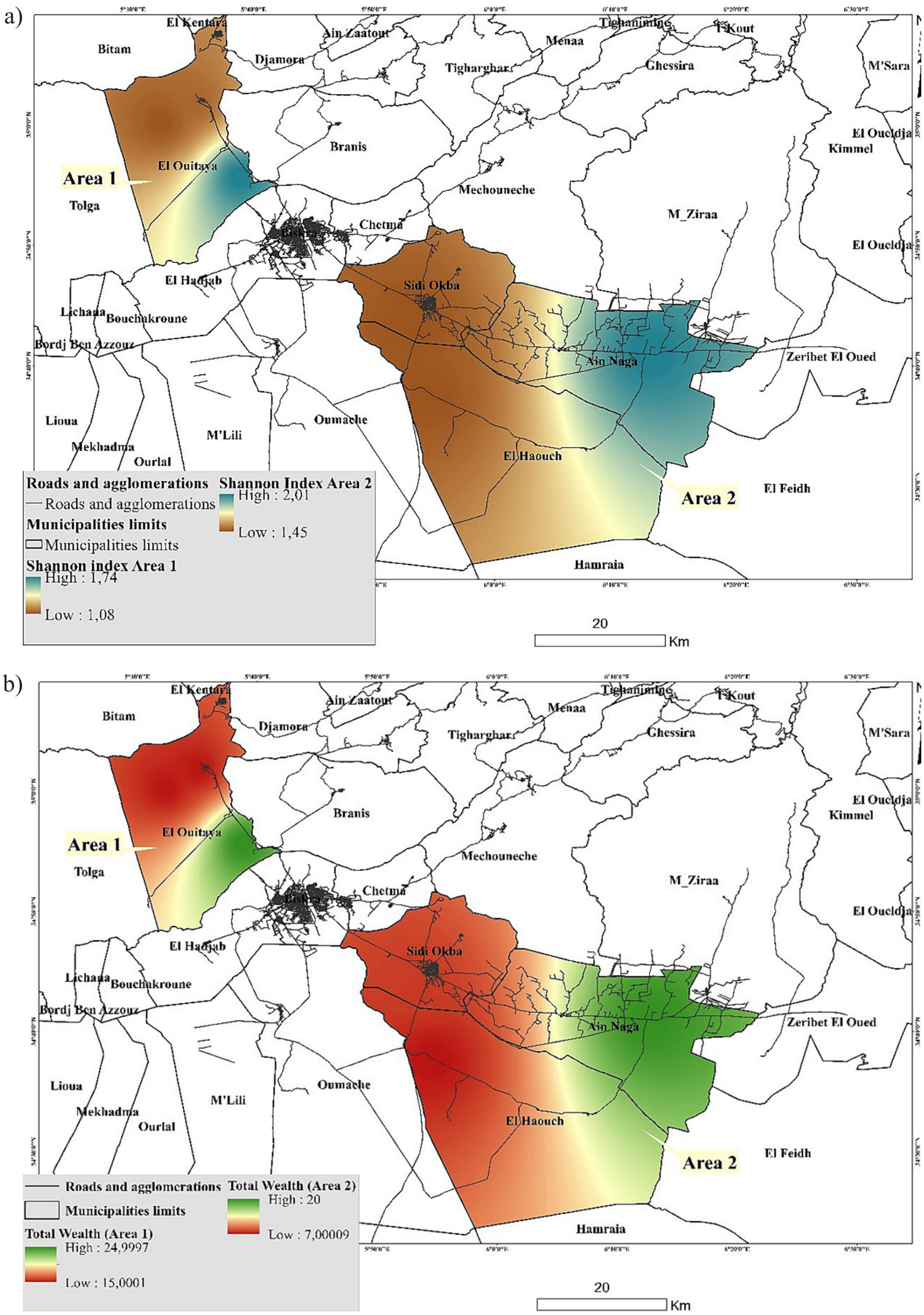

Figure 4. Interpolated spatial distribution of Shannon's informational entropy index (a) and total wealth (b)

(H' = 2.01, E = 0.84) compared to barley and wheat, respectively, in El Haouch and Saada (H' = 1.18, E = 0.30 and H' = 1.45, E = 0.21).

The average number of individuals per species (ratio N/S) was higher in the pepper under greenhouse, particularly at the Dhibia station (153.31) compared to the other stations. In addition, reciprocal index of Simpson (IRS) values oscillates between (0.73 and 0.85) and the ratio IRS/S was lower at Lahzima (0.03) than at the other sites (Table 3).

The geospatial analysis shows the same results obtained as Figure 4, the spatial distribution of Shannon index and total wealth (S) values, where the derivation of the spatial interpolation of the sampling locations was used; shows that higher diversity is located in agricultural vocation areas away from urban agglomerations.

Relationships between diversity parameters

Overall, all aphid diversity parameters were positively correlated in the study area, except for the evenness index the correlation is negative ($r < 0.5$). These correlations were highly significant ($P < 0.05$) for the indices (S, N, Hmax, H', SRI). Conversely, the correlations were not significant for SRI and N/S indices (Fig. 5).

DISCUSSION

The census of aphids' population established in each of the three crops (Pepper under greenhouse, wheat, and barley) includes a great species wealth, belonging to 5 subfamilies, 22 genera, and 32 species. The pepper grown under greenhouse in Lahzima and Dhibia stations is more diverse with 25 and 18 species, respectively, compared to cereal (14 and 8 species that were collected on wheat at Tangour and Saada stations, 15 and 7 species in Dhamrania and El Haouch).

The obtained results are complementary to those reported by Lamarie et al.,[2010], Bakroune [2012], and Menacer [2012], who reported a wealth of 30 species at several sites in Biskra region. Ben Aba and Bengouga [2007] made an inventory of 18 types of barley and fava beans in the same study area. For his part, Hamidi [2013] identified 10 species of aphids in an urban setting in the city of Biskra. In turn, Bakroune [2021] reported the presence of *Aphidinae* with high

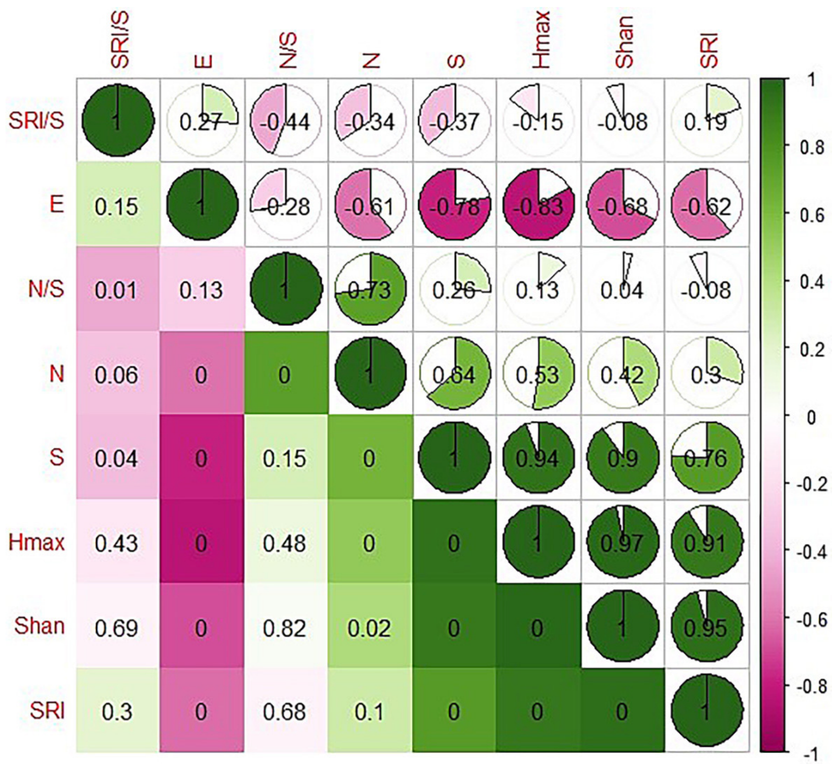

Figure 5. Correlation matrices displaying the correlations between the diversity parameters of aphids captured in the whole region of study (southeast of Algeria). Pearson's correlation tests are given as correlation coefficients (indicated by color and intensity of shading in squares and pie charts and values above the diagonal) and P values (below the diagonal)

intensity, which shows their great ability to colonize agricultural environments. This invasion is due to the influence of different factors as habitat distribution [Sotherton, 1984], microclimate [Honek, 1998] or the presence of prey [Bohan et al., 2000]. In addition, there is a close relationship between entomological diversity and plant cover quality, which can constitute refuge areas and food reserves for species [Dajoz, 1985]. Altieri [1999] indicated that adjacent vegetation, such as weeds, at the peripheries of fields, affects the dynamics of crop colonization by pests, especially if it is taxonomically close to the crop.

The obtained results revealed that *A. gossypii* occupies a predominant place by its strong presence, especially on chili peppers in greenhouses with a rate of 29.69%. According to Christelle [2007], this species is restricted to *Cucurbitaceae* and *Solanaceae*, it tolerates high temperatures, and its maximum pullulating is reached at 24 °C.

According to Bournier [1983], *A. gossypii* is the most common species in cucumber, melon, and pepper under greenhouses, because it is eurythermic compared to other species. The obtained results confirm those of Laamari [2004] on peppers and paprika grown in greenhouses in the region of El-Outaya. The green corn aphid *R. maidis* ranks second with an abundance of 15.23%, followed by the aphid *R. padi* (AR %= 15.08). According to the results obtained by Assabah [2011], these last two species are restricted to cereals. Ketfi [2018], in Constantine region, mentioned the presence of *R padi*, *R. maidi,* and *S. avevae* with a total number of 508 individuals on durum wheat and 531 individuals on soft wheat. In Tunisia, Alhmedi et al., [2007] reported the presence of *R. padi* in a plot of nettles. *R. padi* appears on cereals at a minimum temperature of 15 °C. [Powell et al., 1997]. The abundance of aphids can also be explained by agricultural practices and farm management. Indeed, none of the sites have undergone any phytosanitary treatment.

From the second week of February, the aphid population increases gradually, reaching a peak of 423 individuals on peppers grown under greenhouse in the Dhibia station. This period coincides with an average temperature of 13.3 °C, which is suitable for adults' flight; this confirms the results of Robert [1980], who observed in Rennes (France) that the flight threshold of *R. padi* is around a daytime temperature of 11 °C. During the month of March the number of individuals reached its maximum (929 individuals). This numerical importance is due to the presence of weeds and suitable conditions. During this period, the average temperature was 21.17 °C, the relative humidity was 38.27% and the rainfall was 11.55 mm. According to Jaloux [2010], the spring period is characterized by very important plant richness that explains the installation of new aphid species. This contamination flight experienced a decline in numbers to a decrease of 4% of the overall population in May. Apparently, this period corresponds to the end of the flight period, which coincides with an increase in recorded temperatures, and with the end of the host plant's crop cycle beside the disappearance of plant cover due to drought. According to Robert and Rouze-Jouan [1976], the ability of a species to produce adults periodically depends on the climate, the strain of the aphid, and the presence of the host plant.

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