

Investigation of fluctuation in infestation of citrus whitefly *Dialeurodes citri* (Ashmead, 1885) and its predators in organic citrus orchards under varying climatic conditions: A case study from north-west Algeria

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Investigation of fluctuation in infestation of citrus whitefly *Dialeurodes citri* (Ashmead, 1885) and its predators in organic citrus orchards under varying climatic conditions: A case study from north-west Algeria

Abstract: The citrus pest, *Dialeurodes citri* (Ashmead, 1885), poses a significant threat to citrus crops, impacting growth. Various control methods, including biological measures using natural predators like *Clitostethus arcuatus* (Rossi, 1794), *Chrysoperla carnea* (Stephens, 1836), and *Semidalis aleyrodiformis* (Stephens, 1836), were studied over a year in the Chlef region of northwest Algeria. Results indicated that a temperature range of 19.5 °C to 30.5 °C, with 65 % humidity and no precipitation, favored the emergence of *D. citri* adults. Throughout the study, *S. aleyrodiformis* and *C. arcuatus* emerged as the predominant predators. A strong negative correlation ($r = -0.91$) was observed between *D. citri* abundance and *C. arcuatus* caught on traps. The correlation between nymphal infestation rates and monthly average temperatures was negative ($r = -0.72$), with temperatures ranging from 13 °C to 27 °C and humidity between 47 % and 73 %, conducive to *D. citri* nymphal infestation. Precipitation negatively impacted *D. citri* and its predators, causing a decline in adult numbers during the rainy season. The overarching goal is to establish an integrated biological control system, bolstering the economic viability of citrus cultivation in the region.

Key words: *D. citri*, predators, citrus, climatic parameters, abundance, north-west Algeria

Preučevanje nihanja napada agrumovega ščitkarja (*Dialeurodes citri* [Ashmead, 1885]) in njegovih plenilcev v ekološki pridelavi pri različnih podnebnih razmerah: vzorčna raziskava iz severozahodne Alžirije

Izvleček: Škodljivec agrumov *Dialeurodes citri* (Ashmead, 1885) predstavlja pomembno grožnjo pridelavi agrumov zaradi negativnega vpliva na rast. Različne metode njegovega zatiranja, vključno z biotičnimi, ki vključujejo plenilce, kot so vrste *Clitostethus arcuatus* (Rossi, 1794), *Chrysoperla carnea* (Stephens, 1836) in *Semidalis aleyrodiformis* (Stephens, 1836), so bile preučevane v eni rastni dobi na območju Chlef v severozahodni Alžiriji. Rezultati so pokazali, da je temperatura v območju od 19,5 do 30,5 °C, ob 65 % relativni zračni vlagi in brez padavin, pospeševala pojav odraslih osebkov škodljivca. Skozi celotno obdobje raziskave sta se vrsti *S. aleyrodiformis* in *C. arcuatus* pojavljali kot glavna plenilca. Ugotovljena je bila močna negativna korelacija ($r = -0,91$) med številčnostjo škodljivca (*D. citri*) in plenilca *C. arcuatus* na pasteh. Korelacija med številčnostjo nimf in poprečno mesečno temperaturo je bila negativna ($r = -0,72$), s temperaturo od 13 do 27 °C in relativno zračno vlago med 47 in 73 %, kar je pospeševalo napad nimf škodljivca. Padavine so negativno vplivale na škodljivca in njegove plenilce, kar je povzročilo upad števila odraslih osebkov v deževnem obdobju. Glavni namen raziskave je vzpostaviti sistem integriranega varstva, kar bi pospešilo bolj gospodarno gojenje agrumov na območju raziskave.

Ključne besede: *D. citri*, plenilci, citrus, podnebni parametri, številčnost, severozahodna Alžirija

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1 INTRODUCTION

Citrus is a major fruit crop in many parts of the world (Ahmed & Azmat, 2019, Anjos et al., 2021) including Africa (Oke et al., 2020). Algeria, for example, is the fifth largest citrus producer in Africa with more than 1.478.053 tons generated from 71.470 ha (FAO, 2020). A major problem is that citrus products around the world have been affected by numerous insect pests (Uygun & Satar, 2008), such as the citrus whitefly *Dialeurodes citri* (Wang et al., 2021, Butter & Dhawan, 2021), which can cause high yield losses due to sucking of plant sap by nymphs (Zhang & Li, 2012; Yuan et al., 2017; Boulahia-Kheder, 2021). Recently, Zhang et al. (2019) reported that *D. citri* can be an effective vector for virus CYVCV to citrus. It is also one of the most important citrus pests in the Mediterranean region (Bellows & Meisenbacher, 2007; Martin et al., 2000; Boulahia-Kheder, 2021) including Algeria (Boukhalfa & Bonafonte, 1979).

Indeed, chemical treatment has been one of the best management strategies for controlling the citrus whitefly (Yuan et al., 2017). However, pesticides can have a negative effect on natural enemies and sustainability of crop systems (Corallo et al., 2021). Several environmentally friendly approaches have been developed to control citrus pest (Wuryantini et al., 2021). In the biological control of pests in citrus orchards, predatory insects can play a decisive role and can be a good alternative to chemical treatment (Rattanapun, 2017; Ahmed & Azmat, 2019; Oke et al., 2020; Smaili et al., 2020; Mansour et al., 2021). Their feeding habits are typically polyphagous, and thus help to prevent the buildup of populations of insects that feed on green plants. The identity and abundance of predatory insects has been studied in numerous citrus-producing areas around the world. Indeed, Jacas et al. (2010) reported that biological control has been very effective in managing whiteflies. The lacewings and *Clitostethus arcuatus* (Rossi, 1794), for instance, are the main predators of whiteflies (Sagar et al., 2020).

The ladybird beetle, *C. arcuatus*, is one of the most effective predators of the whitefly since it feeds on all development stages of Aleyrodidae (Yazdani & Samih, 2012). A single beetle consumes more than 50 *D. citri* eggs per day (Onillon, 1975). Another predator is *Chrysoperla carnea* (Stephens, 1836), one of the species of

common green lacewing insects in the Chrysopidae family. Although the adults feed on nectar, pollen and aphid honeydew, the larvae are active predators and feed on whiteflies and other small insects. This species has been used in the biological control of insect pests on crops (Villenave et al., 2005).

The study of insect-pest biology is very important for developing effective biological control strategies (Umeh & Adeyemi, 2011). However, Benmessaoud-Boukhalfa & Chebrou (2014) reported that the study of the dynamics of whitefly populations is complicated because of their polyvoltinism (*i.e.*, having several generations per year), and their intricate and variable interactions with climatic factors such as temperature, humidity, and precipitation, as well as their host plant.

In the current investigation, the relationship between the citrus whitefly pest *D. citri* and its predators *C. arcuatus*, *C. carnea* and *S. aleyrodiformis* (Stephens, 1836) was examined over a one-year period under varying climatic conditions. Organic citrus orchards of the Chlef region in north-west Algeria was utilized as a case study. The long-term aim is to develop an integrated biological control system to enhance the economics of citrus growth in the region.

2 MATERIALS AND METHODS

2.1 STUDY REGION AND EXPERIMENTAL SITES

The current investigation was conducted in the citrus region of Chlef located in the north-west of Algeria close to the coast of the Mediterranean Sea. According to meteorological data provided by the Chlef meteorological station for the period 2009-2017, the climate of the area is semi-arid, with hot summers and mild winters (Mahmoudi et al., 2018). The altitude varied from 83 to 156 m. Precipitation was irregular, and the wettest year was 2012 (525 mm) while the driest year was 2015 (256 mm). The mean annual temperature was 21 °C with an average maximum temperature of 30.8 °C in August. Furthermore, the selection of sampling sites was based on the choice of an orchard infested by citrus whitefly populations that had not been treated with pesticides. The experimental sites were in two localities, Boukadir

Table 1: Description of orchards studied

Study sites	Study sites key	Variety	Age (years)	Area (ha)	Geographic coordinates
Boukadir	BOK	<i>Citrus sinensis</i> 'Thomson Navel'	59	1.2	-36.04391 10.9496
Ouedfodda	ODF	<i>Citrus sinensis</i> 'Valencia'	38	3.2	-36.11569 13.4438

and Oued Fodda (Table 1). The Boukadir investigational site was located 39.6 km from the Oued Fodda citrus orchard.

2.2 METEOROLOGICAL DATA AND INSECT SAMPLING

Monthly maximum and minimum temperature, together with monthly humidity, were recorded from the Chlef meteorological station. The sampling design allows for the collection of data on insect infestation, with a focus on adult insects caught in sticky traps, along with the condition of leaves sampled from different trees. Sampling of insects was made under field conditions approximately every month during the winter periods and fortnightly during the entire season of insect activity (Soto, 1999; Rodrigues & Cassino, 2012) from the first week of July 2015 to the last week of June 2016. For the same sampling periods, the first emerged adults were reported by visual observations on infested young shoots. For each sampling visit, the experiment is replicated and each replication involves selecting 10 trees randomly from each orchard. From each selected tree, 5 leaves are chosen for sampling chosen from different orientations around the tree: North, South, East, West, and the center. With 10 trees sampled and 5 leaves per tree, a total of 50 leaves are sampled per replication and were placed separately in plastic bags to be observed on the laboratory under a binocular microscope. Living nymphs were counted on the leaves to estimate infestation rate of *D. citri* larvae. Nymphal infestation rate and adult abundance in each grove were correlated with climatic parameters. Larval infestation rate equals (number of live larvae/total of larvae)/100. However, adult abundance refers to the mean number of adults for each sampling.

D. citri adults and their predators were caught by suspending randomly three yellow sticky traps (25 x 10 cm) at a height of 1.5 m on the outside of the tree canopy (Calabuig et al., 2015; Eserkaya & Karaca, 2016; Hernández-Landa et al., 2018). The yellow sticky traps were placed diagonally, and spaced 50 meters apart from each other, and replaced at every visit and the insects captured were counted under a binocular microscope (x20, x40, and x80) (Ekbohm & Rumei, 1990). This study employed a total of 120 yellow sticky traps.

2.3 INSECT IDENTIFICATION

Butter and Dhawan (2021) reported that the taxonomists use the characteristic features of the fourth instar pupa of whitefly for species identification.

Insect identification relying solely on external morphology indeed has its limitations, particularly when dealing with species that exhibit morphological variations. In such cases, genetic analysis through DNA barcoding can provide more accurate species identification, with complement morphological observations (Tahir et al., 2018).

Collaborating with taxonomic experts can aid in accurate species identification. In our case, Mr. Streito (INRA Montpellier) and Mr. Reynaud (ANSES Plant Health Laboratory) were actively involved in the identification of whitefly species as well as their predators.

We utilized identification keys based not only on external morphological criteria but also on internal organs within insect bodies, such as the cement gland of *D. citri* female adult's. By incorporating both external and internal characteristics, we were able to enhance the accuracy and reliability of our identification methods. This comprehensive approach allowed us to effectively distinguish between different species.

Indeed, the fourth pupal stages of *D. citri* were collected from infested leaves and prepared for microscopic observation according to the method established by Martin et al. (2000) and Hodges and Evans (2005). Female adults were removed from sticky traps, their cement glands were extracted and observed under optical microscope to confirm the identification of the pupa (Guimarães, 1996). Martin (1987) reported that the identification of adult whiteflies based on external morphology is difficult when the populations of adults captured through the sticky traps are heterogeneous with more than one species. In the current study, only the *D. citri* were registered without other whiteflies species. The adults were 1.2–1.4 mm long, with body and wings covered with white wax powder (Alford, 2012). Identification of adult predators captured was based on external morphology, *C. carnea* adult's body was green and slender (*i.e.*, 15–20 mm long) with golden eyes (Dreistadt, 2012). However, the *C. arcuatus* body was yellow to reddish brown, with an arc-shaped design on the dorsal side (1.2–1.5 mm long) (Klausnitzer, 2011). Although often confused with whiteflies because their bodies and wings are covered with whitish waxy secretion (Lee et al., 2010), *S. aleyrodiformis* is larger and has four wings with front wings larger than the hind ones (McEwen et al., 2001).

2.4 STATISTICAL ANALYSIS

The statistical analysis of the data involved the utilization of Past program version 3.24. This software was chosen for its capability to handle the specific analyses required for our study. In particular, Pearson correlation

tests were employed to assess the relationship between insect abundance and various meteorological parameters. This choice of statistical tool was based on its suitability for examining the linear association between two continuous variables, which aligns with the nature of our research objectives.

Furthermore, significance levels were established at $p < 0.05$, adhering to conventional standards in statistical analysis to denote a statistically significant result. This threshold ensures that observed correlations are unlikely to have arisen by chance alone, thus lending credibility to our findings.

In interpreting the strength of correlations, we followed the guidelines outlined by Schober et al. (2018). According to their classification, correlations with an r -values ranging from 1.0 to 0.9 were considered very strong, indicating a robust and almost perfect linear relationship between variables. Correlations falling between 0.7 and 0.89 were deemed strong, suggesting a substantial linear association. Those ranging from 0.4 to 0.69 were classified as moderate, indicating a moderate degree of linear relationship. Finally, correlations between 0.10 and 0.39 were categorized as weak, signifying a minimal linear association.

By adhering to these established criteria and employing rigorous statistical methods, we aimed to ensure the reliability and validity of our data analysis, thereby enhancing the credibility of the results obtained.

3 RESULTS AND DISCUSSION

3.1 PERIODS OF *D. citri* EMERGENCE

Table 2 shows that the adults of the first generation were recorded in the autumnal period (2015) generally from the end of August to the beginning of September, coinciding with the citrus autumn growth flush, when the mean maximum daily temperature exceeded 37 °C with a mean minimum daily temperature of 24 °C. The

mean daily humidity was estimated at 63 % with an absence of precipitation. Furthermore, the second emergence period was recorded in the spring period in mid-April (2016). In the spring citrus growth flush when the mean maximum daily temperature exceeded 26 °C with a mean minimum daily temperature of 13 °C. The mean daily humidity was estimated at 65 % without precipitation (Table 2).

3.2 NUMBER OF ADULTS OF *D. citri* AND ITS PREDATORS DETECTED IN THE CASE STUDY ORCHARDS

The *D. citri* adults were measured in the Oued fodda (ODF) and Boukadir (BOK) groves. The number of citrus whitefly *D. citri* adult pests was found to be the largest in the BOK orchard compared to the ODF grove. In contrast *C. carnea* adult predators were captured in just very small numbers in each orchard with only some adults being trapped from January through June 2016 (Table 3). For example, for the ODF grove the *C. carnea* predator count was only 0.3 ± 0.39 from January to July 2016, while the *D. citri* adult pest count was 309.6 ± 421.75 . The *C. arcuatus* and *S. aleyrodiformis* adults were more abundant than *C. carnea*. In the ODF grove *S. aleyrodiformis* adults were more abundant from July through December 2015 (19.9 ± 19.70) but their number was small from January through June 2016 (7.5 ± 9.43) (Table 3).

The relationship in seasonal abundance between *D. citri* pests and its predator *C. arcuatus* was analyzed from July 2015 to June 2016 (Figure 1). The number of *D. citri* adults and *C. arcuatus* caught on yellow sticky traps were the largest from July through December 2015 then gradually decreased from January through June 2016 (Figure 1). A moderate positive correlation ($r = -0.42$) in ODF grove was noted and a very strong positive correlation ($r = -0.91$) in the BOK grove between mean abundance of the *D. citri* and its predator *C. arcuatus* adults caught on sticky traps.

Table 2: Dates of first emergence of *D. citri* adults during the sampling period (July 2015-June 2016)

Generation	Citrus grove	Approximate emergence period of earliest adults	Citrus growth flush	T Max (°C)	T Min (°C)	H (%)	P (mm)
1 st	Oued fodda	2015	28 August	37	24	63	0
	Boukadir		1 September				
2 nd	Oued fodda	2016	20 April	26	13	65	0
	Boukadir		23 April				

T Max (°C): mean maximum daily temperature during emergence period of *D. citri*

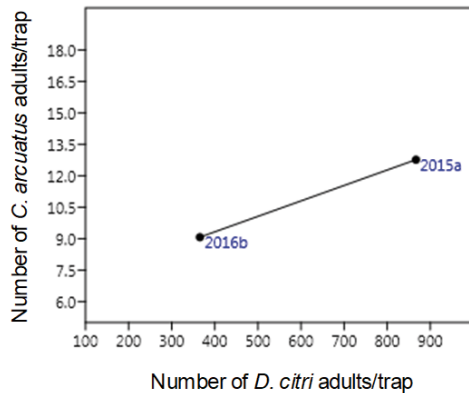
T Min (°C): mean minimum daily temperature during emergence period of *D. citri*

H (%): mean daily humidity during emergence period of *D. citri*

P (mm): daily precipitation amounts during emergence period of *D. citri*

Table 3: Composition and mean abundance of the *D. citri* and their predators *C. arcuatus*, *C. carnea* and *S. aleyrodiformis* caught on sticky traps in citrus orchards (July 2015-June 2016)

Orders	Family	Species	Sampling period	Citrus groves	
				ODF	BOK
Hemiptera	Aleyrodidae	<i>Dialeurodes citri</i> (Ashmead, 1885)	July-Dec 2015	598.4 ± 527.95	1135.3 ± 1652.13
			Jan-June 2016	309.6 ± 421.75	421.4 ± 612.01
Coleoptera	Coccinellidae	<i>Clitostethus arcuatus</i> (Rossi, 1794)	July-Dec 2015	19.4 ± 13.19	6.2 ± 7.05
			Jan-June 2016	16.5 ± 16.81	1.7 ± 2.14
Neuroptera	Chrysopidae	<i>Chrysoperla carnea</i> (Stephens, 1836)	July-Dec 2015	1.9 ± 4.20	0.9 ± 0.81
			Jan-June 2016	0.3 ± 0.39	0.4 ± 0.66
	Coniopterygidae	<i>Semidalis aleyrodiformis</i> (Stephens, 1836)	July-Dec 2015	19.9 ± 19.70	17.42 ± 17.40
			Jan-June 2016	7.5 ± 9.43	1.06 ± 2.42

**Figure 1:** Relationship between the *D. citri* pests and its predator *C. arcuatus* caught on yellow sticky traps in the semi-arid citrus region of Chlef from July 2015 to June 2016. a, Sampling conducted from July through December; b, Sampling conducted from January through June

3.3 RELATIONSHIP BETWEEN TEMPERATURE, HUMIDITY, PRECIPITATION AND NUMBER OF *D. citri* ADULTS

In the two citrus groves, the mean number of *D. citri* adults caught on sticky traps was the highest during September and October (2015) and during April and May (2016), when monthly average temperatures varied from 18 to 30 °C, monthly average humidity varied from 46 to 69 % and with a low precipitation (0 to 27 mm). No *D. citri* adults were trapped in ODF and BOK citrus grove from December 2015 to March 2016 when monthly average temperatures did not exceed 13 °C and with a high precipitation (59 to 130 mm), and a high relative humidity (72 to 77 %)(Figure 2).

In ODF and BOK orchards, the number of adults of *D. citri* was correlated positively with monthly average

Table 4: Correlation between mean adult abundance and climatic parameters

Climatic parameters	ODF citrus grove		BOK citrus grove	
	<i>r</i> -Value	<i>p</i> -Value	<i>r</i> -Value	<i>p</i> -Value
Monthly average temperature (°C)	0.5219	0.0208*	0.4397	0.0116*
Monthly average humidity (%)	-0.4491	0.0936	-0.4549	0.0463*
Monthly precipitation (mm)	-0.5659	0.0903	-0.4378	0.0366*

p < 0.05 (significant) *

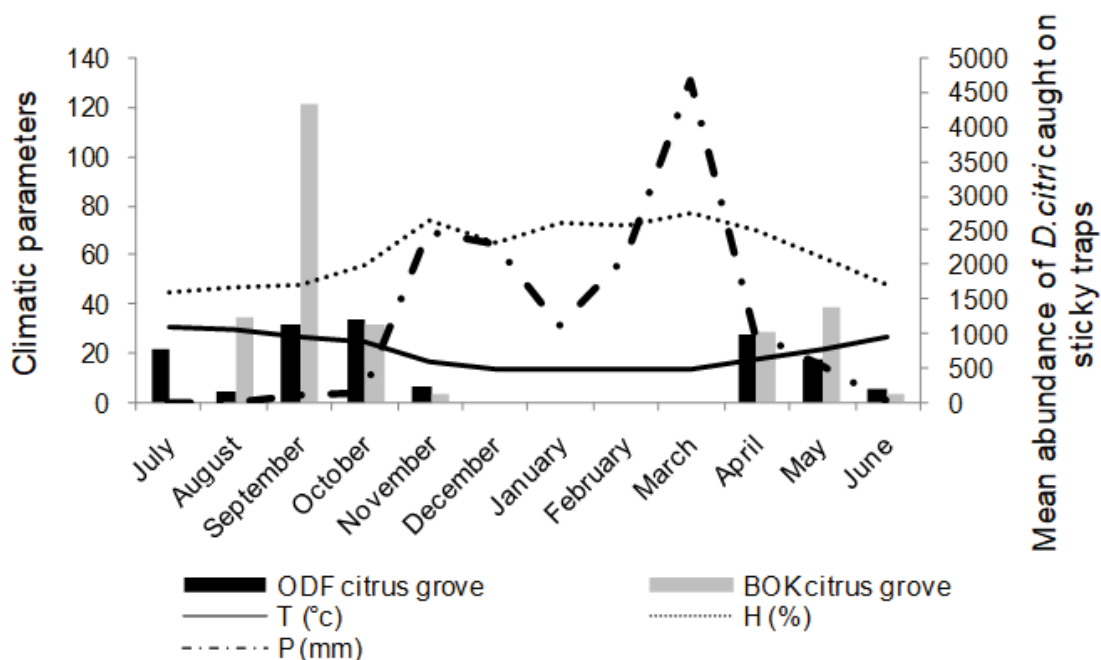


Figure 2: Evolution of *D. citri* captured in relation to monthly average temperatures (T °C), relative humidity (H %) and rainfall (P mm), during the one-year period of study

temperatures ($r_{(ODF)} = 0.52$, $p_{(ODF)} = 0.021$, $r = 0.43$) (Table 4). Whereas the correlation was moderate and negative between monthly data of average humidity, rainfall and mean number of *D. citri* adults ($r_{(BOK)} = -0.45$ & $r_{(BOK)} = -0.43$) in BOK citrus grove.

3.4 RELATIONSHIP BETWEEN TEMPERATURE, HUMIDITY, PRECIPITATION, AND *D. citri* NYMPHAL INFESTATION RATES

The population dynamics of *D. citri* nymphs from July 2015 to June 2016 in the ODF citrus grove showed three infestation peaks appearing respectively in September 2015 (37 %), January 2016 (49 %) and April 2016 (48 %) corresponding to periods of high activity of nymphal populations (Figure 3). Indeed, in the BOK citrus grove, three infestation peaks were recorded in August

2015 (29 %), January (25 %) and April 2016 (26 %) (Figure 3). Additionally, during peaks of the nymphal infestation, the monthly average temperatures varied between 13 and 27 °C, where average monthly humidity data varied between 47 % and 73 % and average monthly rainfall ranged from 3 to 30 mm.

In ODF orchards a significant strong negative correlation ($r = -0.72$) was noted between monthly average temperatures and nymphal infestation rates of *D. citri*. However, a significant moderate positive correlation ($r = 0.62$) was recorded between nymphal infestation rate and monthly average humidity. Results were not significant for nymphal infestation rate in BOK orchard, probably due to a low nymphal infestation rate (Table 5). The relationship between climatic parameters and nymphal infestation rates in the semi-arid citrus region of Chlef from July 2015 to June 2016 are shown in Figure 3.

Table 5: Correlation between nymphal infestation rate and climatic parameters

Climatic parameters	ODF citrus grove		BOK citrus grove	
	<i>r</i> -Value	<i>p</i> -Value	<i>r</i> -Value	<i>p</i> -Value
Monthly average temperature (°C)	-0.7221	0.0080*	-0.2682	0.3992
Monthly average humidity (%)	0.6209	0.0312*	0.2485	0.4362
Monthly precipitation (mm)	0.4444	0.1477	0.1810	0.5734

$p < 0.05$ (significant) *

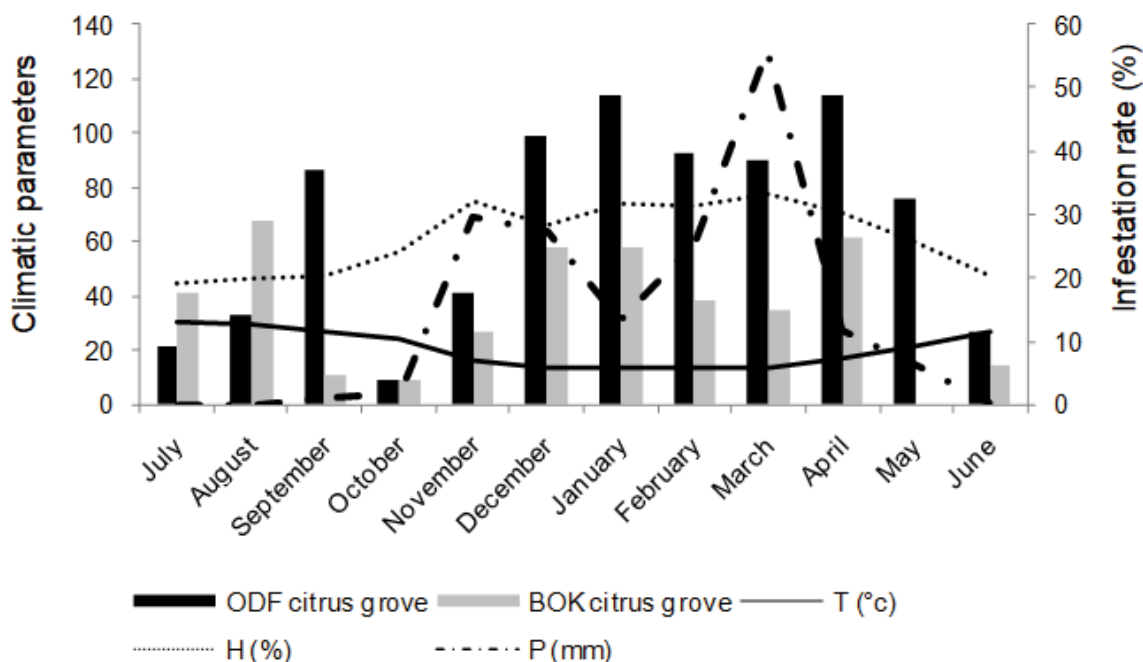


Figure 3: Relationships between climatic parameters and nymphal infestation rate in the semi-arid citrus region of Chlef from July 2015 to June 2016. The principal x-axis illustrates the values of climatic parameters (T (°C), H (%) and P (mm))

3.5 ANALYSIS OF OCCURRENCE OF POLYVOLTINISM & DIAPAUSE FOR *D. citri* PESTS IN CASE STUDY ORCHARDS

The current findings showed two egg laying periods for *D. citri* leading to the appearance of two homogeneous peaks of population clearly separated from each other by a diapause period of 5 to 6 months from November to March. This period of suspended or arrested development, diapause, is usually caused by environmental changes such fluctuations in daylight, temperature, or humidity. These were observed with the current investigation and were like those reported by Saini et al. (2016) in India. Benmessaoud-Boukhalfa & Chebrou (2014) described that the dynamics of whitefly populations is complex because of their polyvoltinism (*i.e.*, having several broods per year), and their interactions with climatic factors such as temperature, humidity, and precipitation, as well as their host plant. Similarly, polyvoltinism was seen by Onillon (1976); Lloréns (1994); Bellows & Meisenbacher (2007), who counted two annual generations of *D. citri* in France, in California and in Spain while three generations per year were found in Japan (Kaneko, 2017). However, unlike in Japan in the sub-humid citrus region in Mitidja plain (north of Algeria), Benmessaoud-Boukhalfa (1987) estimated that the *D. citri*'s diapause period has a duration of 4 to 5 months which would make it unlikely for the pest to have more than two broods a year.

It has been found from the current investigation of the orchards in the Chlef region, that the daily average temperature of 19.5 °C and 30.5 °C in the spring and autumn period, respectively, with a daily average humidity of 65 % with no rainfall, were favorable for the early emergence of the *D. citri* adults. Boukhalfa & Bonafonte (1979) also noted that the beginning of emergence started from mid-April in the sub-humid citrus region of Mitidja. However, in France and Spain, the earliest adults were observed in May (Onillon, 1975, Soto 1999), while Ohgushi & Ohkubo (2005) reported that the first adult emergence appeared in early May to mid-June in Japan. The earliest adults of *D. citri* were found during citrus flushing cycles over April-August and September (2015-2016). It was observed, that the females of *D. citri* lays eggs on young shoots of citrus flush growth. Singh et al. (2021) reported that exclusively during the flush period, *D. citri* population was very active. All of this suggests that colder temperatures increase the diapause phase by suppressing emergence.

3.6 EFFECTIVENESS OF PREDATORS *Chrysoperla carnea*, *Clitostethus arcuatus* AND *Semidalis aleyrodiformis* IN REDUCING POPULATIONS OF CITRUS WHITEFLY PESTS

The authors reported three species of predators:

Chrysoperla carnea, *Clitostethus arcuatus* and *Semidalis aleyrodiformis*. Khan et al. (2020) reported that several insect species belonging to Neuroptera order are a natural enemy of great numbers of pests. *C. carnea* adults however were rarely observed, and their activity was limited as light reduction in the number of adults and eggs of *D. citri*. It can be argued that the effect of the predator *C. carnea* is not significant in decreasing the populations of the citrus whitefly pest. This conclusion is supported by the results of the current study as shown in Table 3. In contrast, large captures of *C. arcuatus* and *S. aleyrodiformis* adults were observed in the citrus orchards in the present investigation (Table 3). Benmessaoud-Boukhalifa (1987) reported that *C. arcuatus* is the most efficient predator of *D. citri* in Algeria. The ladybird beetle *Clitostethus arcuatus* is one of the most effective predators of the whitefly. This ladybird feeds on all development stages of Aleyrodidae (Yazdani and Samih, 2012). A single beetle consumes more than 50 *D. citri* eggs per day (Onillon, 1975).

In Egypt, *C. arcuatus* is considered as the most important predator of *D. citri* with more of 41.9 % of the total number of predators (El-Husseini et al., 2018).

A positive correlation was found between the *D. citri* count and the predator *C. arcuatus* adults, which means that this predatory coccinellids feeds on whitefly but without significantly reducing their abundance. Thus, it can be reasoned that *C. arcuatus* can be efficient against *D. citri* but only when this whitefly lays few numbers of eggs (EPPO, 2004). In addition, the influence of predators on *D. citri* populations decreased with increasing temperature (Bale et al., 2002, Thomson et al., 2010). Increased precipitation also greatly reduces their ability to move and search for prey (Thomson et al., 2010). However, Thöming & Knudsen (2021) reported that the diversity of beneficial insects was dependent on vegetation diversity.

3.7 DYNAMICS OF EFFECT OF TEMPERATURE, PRECIPITATION & HUMIDITY ON INSECT INFESTATION RATES

Dreistadt (2012) reported that the honeydew secreted by *D. citri* nymphs attracts ants, which can disrupt the activity of whitefly predators. According to Byrne (1991), whitefly population dynamics depends on different climatic factors and natural enemies. Climatic parameters such as temperature, rainfall and relative humidity are known to impact the population dynamic of *D. citri* (Kumar, 2001; Rashid et al., 2003; Saini et al., 2016). The present study revealed that temperature may influence the dynamics of *D. citri* nymphal population because a

strong negative correlation was found between nymphal infestation rate and monthly average temperatures. This correlation revealed that the *D. citri* nymphal infestation peaks occurred in winter and autumn which were cold to mild periods with monthly average temperatures varying between 13 and 27 °C. The same results were obtained by Saini et al. (2016) who reported a negative correlation between nymphal population of *D. citri* and the mean minimum and maximum temperature.

From the correlation results, a decrease in monthly average temperature resulted in an increase in the *D. citri* nymphal infestation rate (Figure 3). Similarly, Bernardo et al. (2006) also signaled the strong effect of temperature on the development rate of insects. However, a moderate positive correlation was found between *D. citri* nymphal infestation rate and monthly average humidity. Unlike the temperature, increased monthly average humidity resulted in an increase of *D. citri* nymphal infestation rate with values varying between 47 % and 73 % during the *D. citri* nymphal infestation peaks (Figure 3). These results were consistent with a study by Kumar (2001) that demonstrated that humidity varying between 60-75 % was favorable for development of *D. citri*. Likewise, several investigations have also focused on the impact of relative humidity on populations of *D. citri* (Mansour et al., 2021; Zeb et al., 2011; Saini et al., 2016).

The correlation analysis between weather parameters and mean adult abundance of *D. citri* revealed that the monthly average temperatures exhibited a significant moderate positive influence. Two peaks of abundance were recorded in spring and autumn period, seasons which are characterized by higher monthly average temperatures (18 to 30 °C) with less rainfall. In particular, an increase in monthly average temperature resulted in an increase of *D. citri* adult abundance. While monthly average humidity and monthly precipitation had a significant moderate negative correlation with the number of *D. citri* adults caught on sticky traps, this indicated that a decreased monthly average humidity and monthly precipitation resulted in an increase of *D. citri* adult abundance. In addition, the absence of *D. citri* adults on the sticky traps was observed in the winter period when monthly precipitation exceeds 130 mm and monthly average humidity varies between 72 to 77 %.

In closing, with the present study a decrease in *D. citri* adult count was noted during rainy periods and an increase was seen during dry periods. This was like that cited by Rashid et al. (2003) who reported that precipitation and humidity affect the abundance of whitefly populations. Insects can be affected in their development by environmental factors (Bale et al., 2002). Indeed, global warming causes critical changes in population abundance of insects (Sharma, 2014). Finally, there is a need

to set up an integrated control system against insect pests (Saini et al., 2016). This must be coordinated with studies of their population dynamics.

4 CONCLUSIONS

This article may facilitate the implementation of an integrated pest management program in Chlef citrus region by understanding the tri-trophic interaction between host plants, *D. citri* populations and their predators under the impact of the particular climatic conditions of the region.

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4.2 LIST OF ABBREVIATIONS

BOK: Boukadir; ODF: Oued fodda; FAO: Food and Agriculture Organisation; *D. citri*: *Dialeurodes citri*; *C. arcuatus*: *Clitostethus arcuatus*; *S. aleyrodiformis*: *Semidalis aleyrodiformis*; *C. carnea*: *Chrysoperla carnea*; T Max: maximal temperature; T Min: minimal temperature; H (%): humidity; P (mm): precipitation. EPPO: European and Mediterranean Plant Protection Organization.

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