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Phenology of two scale insects, *Coccus hesperidum* and *Icerya purchasi* (Hemiptera: Coccomorpha) on *Citrus* in Mostaganem, Algeria

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Original article

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Abstract. In Mazagran, Mostaganem Province, Algeria, the seasonal variation in abundance of the scale insects (Hemiptera: Coccomorpha) *Coccus hesperidum* LINNAEUS, 1758 (Coccidae) and *Icerya purchasi* MASKELL, 1879 (Monophlebidae) was studied in an orchard on two host plant species, orange (*Citrus sinensis*) and lemon (*C. limon*) between December 2018 and November 2019. Every ten days, samples of leaves were collected for monitoring insect numbers. In *C. hesperidum* on orange and lemon trees respectively, there were three or four population peaks annually (P<0.0001). In *I. purchasi*, there were three generations annually (P<0.0001). In both scale insect species their abundance was correlated with temperature (P<0.0001 for *C. hesperidum*, and P=0.010 for *I. purchasi*) but not with relative humidity levels. Lemon trees had the higher scale insect abundance on 50% of days sampled, for both *C. hesperidum* and *I. purchasi* (P<0.005), whereas orange had lower numbers of both scale species. *C. hesperidum* and *I. purchasi* occurred on all three sample plots; numbers of both species (particularly *C. hesperidum*) showed a positive relationship with wind speed (P<0.0001 and P=0.002, respectively), as strong winds probably picked up and carried crawlers into the sample plots situated downwind.

Key words: Sternorrhyncha, population, generation, species interaction.

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I. INTRODUCTION

The scale insects (Coccomorpha) belong to the order Hemiptera (the true bugs), suborder Sternorrhyncha, and are found on all continents except Antarctica (KONDO et al. 2008; PELLIZZARI & GERMAIN 2010). Until about the middle of the twentieth century, most scale insect researchers placed all scale insects in the family Coccidae, but subsequently a number of subfamilies were elevated to family rank and the superfamily Coccoidea came into common use (WILLIAMS & HODGSON 2014). SZWEDO et al. (1990) first used the infraorder Coccomorpha for the scale insects, to bring taxonomic terminology in line with the use of infraorders in other parts of the order Hemiptera, and WILLIAMS & HODGSON (2014) endorsed its use.

Scale insects are the sister group to the aphids (infraorder Aphidomorpha). They are obligate sap-sucking plant parasites found almost anywhere plants grow. Along with the majority of other plant-feeding Hemiptera members, they are the only insects that feed solely on plant juices, usually on phloem sap (DOUGLAS 2006; HARDY 2018; GULLAN & COOK 2007), and are important members of ecosystems.

Some introduced scale insect species are extremely invasive pests and may be difficult to identify (HARDY 2018; MILLER et al. 2005).

The popular term 'scale insects' refers to the protective cover, usually waxy, that many scale species secrete (HODGSON & WILLIAMS 2018). They are highly specialized for plant parasitism and some are extremely small, the adult females ranging in size from 0.5 to 18 mm. Extreme sexual dimorphism is a feature of scale insects: adult females are wingless, with an oval or circular and flat to fairly convex body, sometimes bud-shaped, whereas the adult males are smaller, typically have one pair of wings, are inconspicuous, do not feed, and live for only a few days (PELLIZZARI & GERMAIN 2010; SIRISENA et al. 2016).

Some important scale insect pests that attack *Citrus* trees are the brown soft scale, *Coccus hesperidum* LINNAEUS, 1758 (family Coccidae) and the Australian fluted scale, *Icerya purchasi* MASKELL, 1879 (family Monophlebidae). Both species have long stylets for piercing plant tissues to extract phloem sap from the leaves, twigs and branches. They cause sap loss and produce sugary honeydew waste on which sooty moulds grow; the black moulds block light and air from the leaves, impairing photosynthesis. *Coccus hesperidum* is a mainly parthenogenetic species (GARCÍA MORALES et al. 2016); *I. purchasi* is unusual in being hermaphrodite and capable of self-fertilisation (GOLAN 2008; MONGUE et al. 2021). Both species are cosmopolitan wherever *Citrus* is grown, and are polyphagous: *C. hesperidum* feeds on plant hosts belonging to 135 families and 403 genera and has been recorded from 147 countries, while *I. purchasi* feeds on hosts belonging to 85 plant families and 212 genera and has been recorded from 148 countries worldwide (GARCÍA MORALES et al. 2016).

To create a pest management strategy, information on the life history and phenology of the target pests is essential. The objective of this study was to evaluate the phenology of two scale insect pest species, *C. hesperidum* and *I. purchasii,* in Mazagran, Mostaganem Province, Algeria.

II. MATERIAL AND METHODS

Sampling

The study was carried out between December 2018 and November 2019. The sampling was done in the *Citrus* orchard of the Experimental Farm of the Department of Agronomic Sciences, Abdelhamid Ibn Badis University of Mostaganem, Algeria, at 35°53′35″ North, 0°4′44″ East, and an altitude averaging 147 m above sea level. The experimental farm is 63.24 hectares large and is located between the municipalities of Mostaganem to the north, Mazagran to the west, Hassi Mamèche to the south, and Douar Djedid to the east. Since 2008, the orchard has never been sprayed with insecticides and has been irrigated. The orchard was divided into plots with gaps of few meters between them. Three plots were chosen (Fig. 1) with an area of 1.2 ha, 1.3 ha, and 1.2 ha respectively, a total of 3.7 hectares, all containing trees about 20 years old planted at 4×5 m spacing. The selected plots contain a mixture of orange and lemon trees in different proportions: Plot 1 had 18% *Citrus sinensis* and 82% *C. limon*; Plot 2 had 50% of each host species, and Plot 3 had 80% *C. sinensis* and 20% *C. limon*.

All three plots are situated on a south-south-east facing slope, with Plots 1 and 3 sloping at 8.7% and 7.83% respectively; Plot 2 is more-or-less level, with a slope of only 0.58%. Plots 1 and 2 are also tilted towards the East across their widths (2.2% and 3.16% respectively) whereas Plot 3 is less strongly tilted (1.85%), in a slightly more westerly direction.

Fig. 1. Left: aerial photograph of Mostaganem with the land sloping downhill towards the top of the photograph; the sample plots are ringed in blue. Centre: enlarged photographs of the sample plots, each with the slope of the land indicated. Right: directions of prevailing winds during the year of sampling.

The study of the leaf infestation by *C. hesperidum* and *I. purchasi* involved a random selection of 30 *Citrus* trees, each sample tree being marked by a sticky band. The sampling was conducted on the same trees each time, and observations were made three times per month. From each tree, 15 leaves were taken (three leaves from the side of the canopy facing each cardinal direction (North, South, East, West) and three from the middle of the canopy), for examination. The leaves were gathered and placed in plastic bags, labeled with the sample data (date, plot number, and *Citrus* species), and then taken to the laboratory for observation.

All the samples were examined in the laboratory using a binocular dissection microscope with a magnification of 40×. The abundance assessment method used was developed by VASSEUR & SCHVESTER (1957); for each scale insect species this involved the enumeration of live individuals of all developmental stages from egg to adult, on both the lower and upper surfaces of the leaves. The scale insect species in the leaf samples were identified by Dr Gillian W. WATSON (Natural History Museum, London, U.K.) as *Coccus hesperidum* LINNAEUS and *Icerya purchasi* MASKELL.

Meteorological data for each sampling date during the 2018/2019 season was obtained from the Mostaganem meteorological station. Temperature, humidity, wind speed, and wind direction were all measured using a Davis Vantage Pro2 instrument with a Weather Link data logger, which connects to a PC and has the great advantage of stating accuracies for all of its measured quantities (BELL et al. 2013).

Statistical analysis

Seasonal fluctuations in scale insect pest abundance were depicted in bar charts using data from the seasonal monitoring of *I. purchasi* and *C. hesperidum* populations on two host species orange (*Citrus sinensis*) and lemon (*C. limon*) in Plots 1, 2 and 3 (Fig. 1). To test the level of infestation of each scale species throughout the year, we used analysis of variance (ANOVA) in XLSTAT software (ADDINSOFT 2022).

Spearman test correlation was used to test for correlation between the abundance of each scale insect species (*I. purchasi* and *C. hesperidum*) and temperature (T°), relative humidity (RH) and wind speed (WS) values on the sampling dates.

To test whether the abundance of each scale insect species differed significantly between orange and lemon tree hosts, we used box plots to abundance of each scale insect species on each host species in each sample plot. The least significant difference (LSD) and Tukey's *post hoc* tests were used for pairwise comparisons.

We used scatter plots to show the abundance of each scale insect species on each plot, to see if the abundance of each *I. purchasi* and *C. hesperidum* species was evenly distributed across three plots. LSD *post hoc* and Duncan's tests were used for pairwise comparisons, to test whether the group proportions were equal.

III. RESULTS

Number of generations annually

Both the scale insect species (*C. hesperidum* and *I. purchasi*) were present in all three sampling plots. The abundance of *C. hesperidum* on orange and lemon trees fluctuated throughout the year (Fig. 2), with the peak levels of infestation being highly sig-

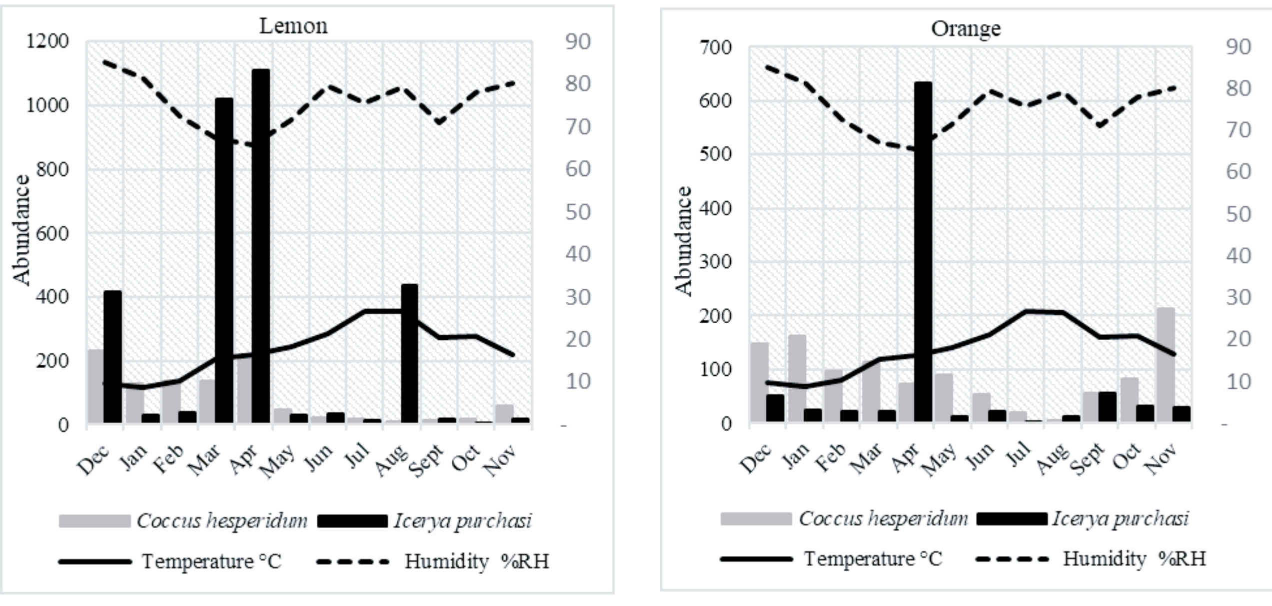

Fig. 2. Monthly counts of *Coccus hesperidum* and *Icerya purchasi* from all three plots combined, plotted against temperature (°C) measured by Mostaganem meteorological station, during the research period 2018-2019.

nificant ($P<0.001$, $R^2=0.006$, $F=10.95$). There were three or four peaks annually (i.e. generations) depending on the host species, with the peaks occurring in different months on each host. On lemon there were three population peaks (in December, February and April), whereas on orange there were four peaks (in November, January, March and May). The optimum temperature range for *C. hesperidum* was between 9 and 26°C. On the other hand, there was no correlation between *C. hesperidum* abundance and relative humidity ($P=0.808$, $r=0$).

The abundance of *I. purchasi* on citrus trees fluctuated throughout the year, with the peak levels of infestation being highly significant ($P<0.0001$, $R^2=0.028$, $F=50.314$). On both lemon and orange, *I. purchasi* numbers attained a very high peak in March and/or April (Fig. 2 bar charts) and then fell sharply. ln the data concerning the lemon tree, there were smaller additional peaks in December and August, and on orange trees there were minor peaks in September and December. The peaks indicate that *I. purchasi* has three generations annually at Mostaganem. The optimum temperature range for *I. purchasi* was between 10 and 26°C; *I. purchasi* numbers showed no correlation with Relative Humidity ($r=0.004$, $P=0.334$).

On 50% of sampling days in all three sample plots, the higher scale insect numbers recorded were on lemon trees for both *I. purchasi* and *C. hesperidum* (up to 110, and up to 90 individuals, respectively); on the same sampling days in the same plots, the lowest numbers of both scale species were recorded on orange trees (Fig. 3).

Figure 4 shows the dispersion of *C. hesperidum* and *I. purchasi* during the year over the three *Citrus* plots studied. Scatter plots (SP) were used to determine the dispersion density on the three sample plots of *I. purchasi* (on the Y axis), and *C. hesperidum* (on the X axis), to test the abundance of the two scale species on each plot. For each plot, a common point for the two species of scale insect is provided. Each point for each sample plot represents the abundance of the two scale insect species on that sample date. Overall, the abundance of *I. purchasi* and *C. hesperidum* on each sampling plot shows a positive relationship. Each plot's ellipses associated with *I. purchasi* and *C. hesperidum* abundance overlap with each other, supporting the null hypothesis that there was no significant difference between the plots ($P=0.540$, $R^2=0.001$, $F=0.377$).

A Spearman correlation coefficient study of the abundances of *C. hesperidum* and *I. purchasi* in relation to wind speed showed that the population density of each species fell when wind speed increased, indicating that in both species the tiny crawlers are picked up and carried away by strong winds. There was a significant positive correlation in *C. hesperidum* ($P<0.0001$, $r=0.080$), showing that still air favours crawlers settling locally, whereas strong winds blow them out of the sample plot (probably dispersing them over longer distances). However, there was only a slight negative correlation between wind speed and insect numbers in *I. purchasi* ($P=0.002$, $r=0.044$) (Fig. 4), indicating that for this species, strong winds blow only small numbers of crawlers out of the trees.

IV. DISCUSSION

Scale insects are among the world's most troublesome agricultural crop pests. GOLAN et al. (2015) documented how two host-plant species (lemon and ferns) were impacted by *C. hesperidum*; due to the in-

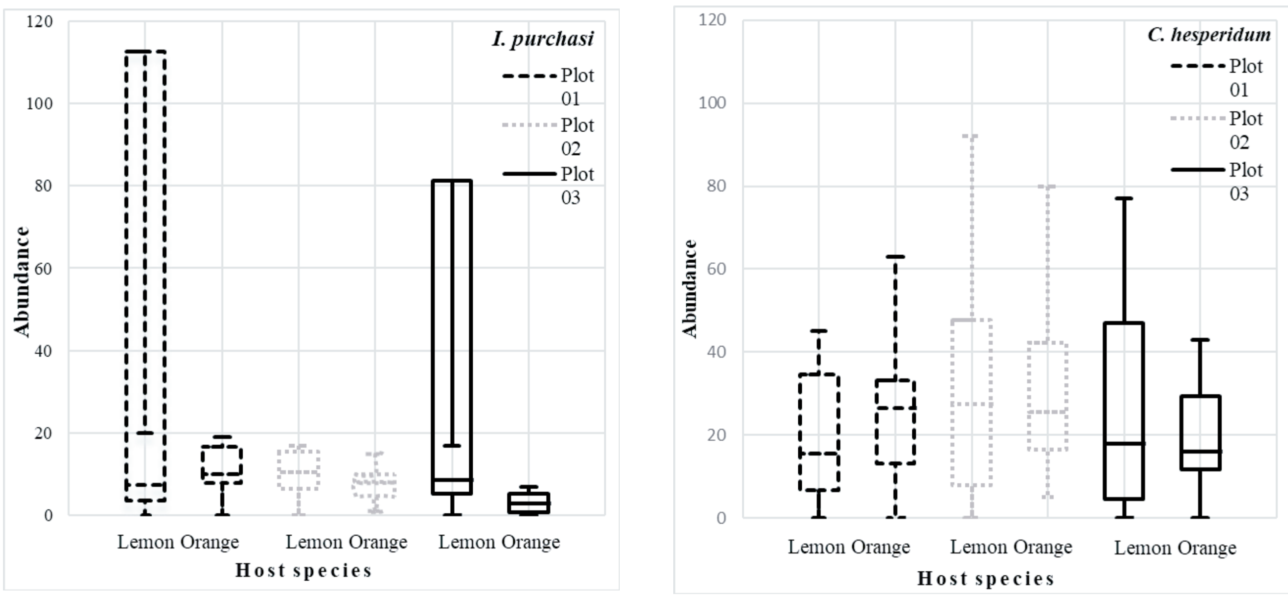

Fig. 3. Box plots showing the abundance of *Icerya purchasi* (left plot) and *Coccus hesperidum* (right plot) on orange and lemon hosts on three sample plots, December 2018 to November 2019 ($P<0.005$, $R^2 = 0.012$, $F = 7.785$).

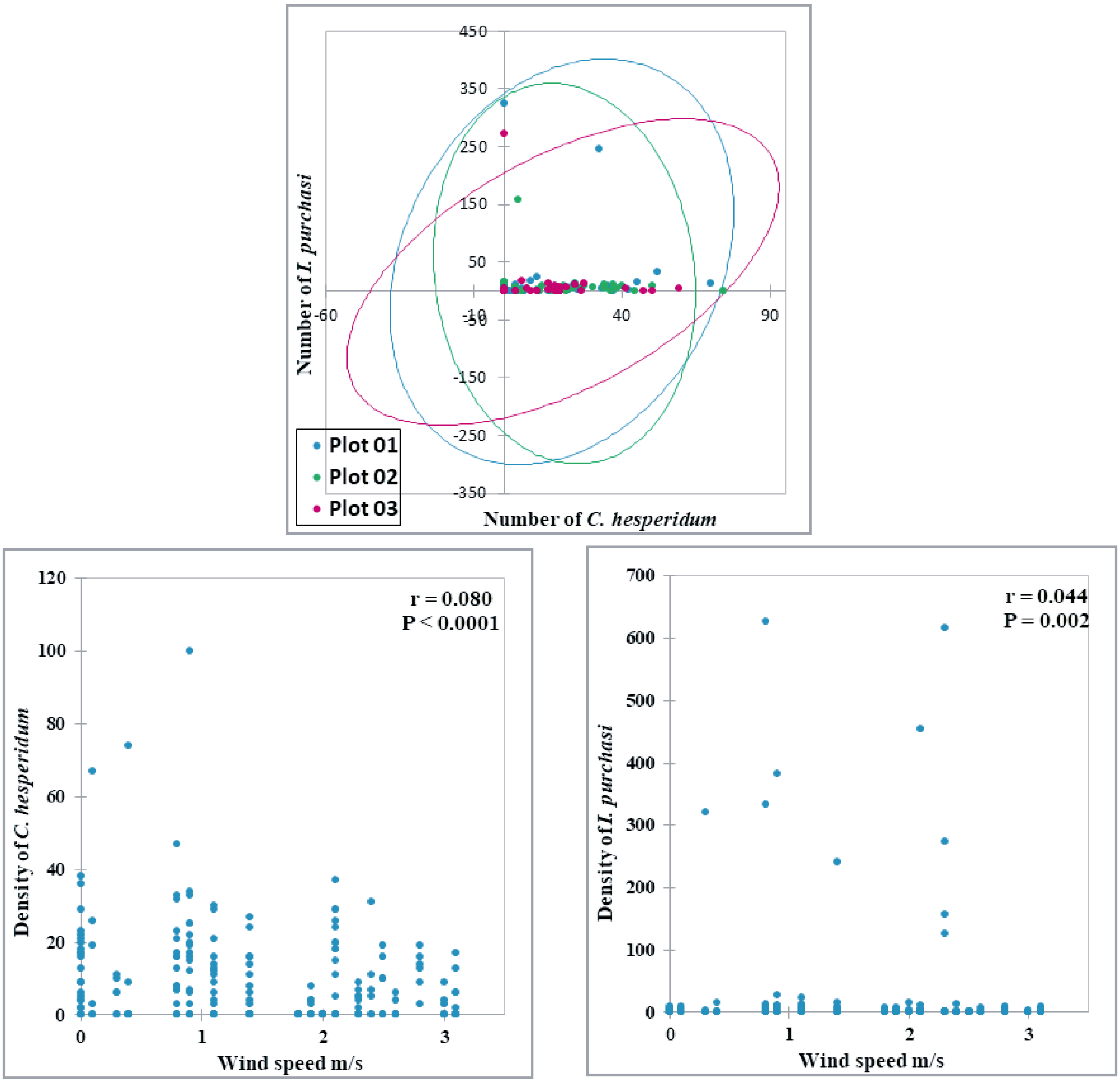

Fig. 4. Top: A scatter analysis showing the distribution of the populations of two scale insect species between the three study plots; the overlap of the oval areas indicates no significant difference in scale numbers between the plots. Bottom: Insect numbers of each species in relation to wind speed measured by Mostaganem meteorological station, during the research period 2018-2019.

festation, the host chlorophyll and carotenoid content and the levels of three photosynthetic activity markers were reduced. The amount of chlorophyll in the leaves is the best predictor of photosynthetic output and overall plant health (MAO et al. 2007; ZARCO-TEJADA et al. 2002). Understanding the phenology of pest scale insect species and implementing effective management tactics requires a thorough understanding of a phytophagous pest invasion (KIM et al. 2011).

In a past study in the Mitidja region of Algeria, three scale insect species were documented on *Citrus*: two species of Coccidae (*C. hesperidum* and *Saissetia oleae* (OLIVIER, 1791)) and one monophlebid (*I. purchasi*) (AROUA et al. 2019). In the present study of *Citrus* trees in Mostaganem (Algeria), two scale insect species were found in 2018-2019 (*C. hesperidum* and *I. purchasi*). Our study found that in Mostaganem, *C. hesperidum* has three to four generations annually on *Citrus*, with the times of the population peaks differing slightly between hosts, occurring in December, April, and February on lemon but in November, January, March and May on oranges (Fig. 2). This finding is consistent with that of CHAPOT & DELUCCHI (1964) on *Citrus* in Morocco, who recorded population peaks in early spring, July, and September-October; and with that of MOHAMED (2014) in 2013-2014, who identified four generations annually on mango trees in Egypt. The small differences between these records must be attributable to variance in local conditions like climate, and variations in host plant species / varieties and quality. Six annual generations of *C. hesperidum* have been recorded in Israel, three in South Africa on *Citrus* plants, two to three in both western Sicily and southern France, and one in Sardinia and eastern Sicily (BEN-DOV & HODGSON 1997).

In this study it was found that three annual generations of *I. purchasi* occur on lemon and orange trees in Mostaganem, Algeria, peaking in December, April and August on lemon, and in December, April and September on orange (Fig. 2), as was found also by BOUKHOBZA et al. (2020) on *Citrus* in Sidi Moussa (Central Mitidja, Algeria). In Italy and Spain, LLORENS CLIMENT (1990) also recorded three generations annually, peaking in February, June and September; while CHAPOT & DELUCCHI (1964) mentioned four generations in Moroccan coastal areas: one from February to June, the second from June to August, a third from August to October-November, and a fourth from December to February. KIM et al. (2011) detected two generations of *I. purchasi* in *Citrus* orchards in Jeju, Korea: the first generation lasted from late May to late September, and the overlapping second generation occurred from early September onwards. Again, the differences between these records must be attributable to variance in local conditions like climate, and variations in host plant species / varieties and quality.

Coccus hesperidum numbers peaked at different times from *I. purchasi*. *Icerya purchasi* is thought to have originated in Australia or New Zealand (BALACHOWSKY 1935) but is now found wherever commercial *Citrus* is grown (CLIMENT 1990). In Algeria it overwinters in just one developmental stage, so it has three highly synchronized generations each year. *Coccus hesperidum* is probably of a more temperate origin and does not have such clearly synchronized generations, suggesting that in Algeria, it overwinters as a mixture of developmental stages; therefore the generations overlap.

A period of population regression is evident in both scale species during the very hot, dry summer months (*C. hesperidum* in June, July and August, and *I. purchasi* in June and July (Fig. 2)), probably due to the amount of daylight, temperature and humidity not matching the species' optimal requirements. Our results are consistent with those of ALIAKBARPOUR et al. (2010).

It is known that scale insects mostly disperse at the active first-instar nymphal stage, sometimes known as a crawler (GREATHEAD 1997), which has relatively lengthy legs and antennae and a comparatively tiny body with very long lateral setae or wax filaments, probably adaptations for short-range dispersion (MILLER & DENNO 1977). Many scale insects are dispersed by the wind and may be carried from their natal trees over distances ranging from a few meters to several kilometers, and even a few hundred kilometers (HANKS & DENNO 1998). At 7.5 inches (=19.05 cm) and 250 yards (=228.6 m) from the source of the insects, BROWN (1957) and TIMLIN (1964) detected the influence of wind on coccoid dissemination, and also mentioned the passive transport of crawlers on infested plant material transported in trade.

The southwest winds in December and April coincide with the production of crawlers by *C. hesperidum* and *I. purchasi* (Figs 1, 4). Numbers of both scale species show a negative correlation with wind speed, especially in *C. hesperidum* ($P<0.0001$) but much less so in *I. purchasi* ($P=0.002$). Strong winds blow the crawlers out of the trees, preventing them settling locally, so they probably settle further downwind. This agrees with GREATHEAD's (1972) findings that wind speeds around 2 m/s carried crawlers away downwind.

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