SCIENTIFIC PAPER

Dactylopius opuntiae (Cockerell) (HEMIPTERA: DACTYLOPIIDAE) POPULATION FLUCTUATIONS AND PREDATORS IN TLALNEPANTLA, MORELOS, MEXICO

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*Dactylopius opuntia*e (Cockerell) (HEMIPTERA: DACTYLOPIIDAE) POPULATION FLUCTUATIONS AND PREDATORS IN TLALNEPANTLA, MORELOS, MEXICO

Dactylopius opuntiae (Cockerell) (Hemiptera: Dactylopiidae) fluctuación poblacional y sus depredadores en Tlalnepantla, Morelos, México

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ABSTRACT. The cochineal scale insect, *Dactylopius opuntiae* (Cockerell), is a key pest of *Opuntia* spp. (Plantae: Cactaceae). It reduces the plants' useful-life and affects production of their cladodes and fruit. Chemical control is the main strategy, but it is inefficient and a risk for environment and human health. For this reason, other management strategies are required, for example biological control with entomophagous insects. To this end, the population dynamics of *D. opuntiae* and its predators were studied in three commercial plantations of *Opuntia ficus-indica* (L.) Miller cactus grown for production of tender cladodes in Tlalnepantla, Morelos. The study was conducted from February to August 2008. Weekly random samples were taken of adult females from 50 colonies in each plantation. Abiotic factors recorded in the three sites were precipitation, temperature and relative humidity. Pearson correlation indexes were determined for the pest, its predators and the abiotic factors. The entomophagous insects *Leucopis bellula* (Diptera: Chamaemyiidae) and *Sympherobius barberi* (Neuroptera: Hemerobiidae) were the most correlated with *D. opuntiae,* $r = 0.3931$, $p = 0.0005$ and $r = 0.3075$, $p = 0.0073$, respectively. Relative humidity ($r = -0.5648$, $p < 0.0001$) and number of days with observable precipitation ($r = -0.5621$, $p = 0.0189$) negatively affected *D. opuntiae* abundance, while mean temperature favored population growth ($r = 0.3899$, $p = 0.0039$).

Key words: Prickly pear, biological control, natural enemies, *Leucopis bellula*, *Sympherobius barberi.*

RESUMEN. La cochinilla silvestre del nopal, *Dactylopius opuntiae* (Cockerell), es la plaga clave del cultivo de nopal, *Opuntia* spp. (Plantae: Cactaceae), ya que reduce la vida útil de las plantas y afecta la producción de sus cladodios y frutos. El control químico es la principal estrategia, aunque ineficiente y riesgosa para la salud y el ambiente, por lo que se requiere implementar otras estrategias de manejo como el control biológico con insectos entomófagos. Para ello, se estudió la dinámica poblacional de *D. opuntiae* y sus depredadores en tres huertos comerciales de nopal verdura, *Opuntia ficus-indica* (L.) Miller, en Tlalnepantla, Morelos. Dicho estudio se realizó durante el periodo de febrero a agosto de 2008, donde se realizaron muestreos semanales, en los cuales se recolectaron al azar 50 colonias de hembras adultas por huerto y se registraron los factores abióticos de precipitación, temperatura y humedad relativa en los tres predios. Posteriormente, se determinó el índice de correlación de Pearson entre las poblaciones de la plaga, sus depredadores y los factores abióticos. Los entomófagos *Leucopis bellula* (Diptera: Chamaemyiidae) y *Sympherobius barberi* (Neuroptera: Hemerobiidae) presentaron los mayores valores de correlación con *D. opuntiae,* $r = 0.3931$, $p = 0.0005$ y $r = 0.3075$, $p = 0.0073$, respectivamente. Por otro lado la humedad relativa ($r = -0.5648$, $p < 0.0001$) y el número de días con precipitación observable ($r = -0.5621$, $p = 0.0189$) afectaron negativamente la abundancia de *D. opuntiae* mientras que la temperatura media favoreció su crecimiento poblacional ($r = 0.3899$, $p = 0.0039$).

Palabras clave: Nopal, control biológico, enemigos naturales, *Leucopis bellula, Sympherobius barberi.*

INTRODUCTION

The soft scale *Dactylopius opuntiae* (Cockerell), 1896 (Hemiptera: Dactylopiidae) is a key pest that causes economic losses in *Opuntia* spp. (Cactaceae:Opuntiales) crops in Brazil (Oliveira *et al*., 2013), Mexico (Vanegas-Rico *et al*., 2010, Chávez-Moreno *et al*., 2011), as well as in Turkey, Lebanon, Israel (Spodek *et al*., 2014), and other parts of the world (Portillo, 2009; García-Morales *et al*., 2016). Mexico is the center of origin and domestication of *Opuntia ficus-indica* (L.) Miller (Kiesling, 1999), which is the most commercially used cactus species in the world (Griffith, 2004). The greatest diversity of Dactylopiidae is also found in Mexico; of these, *D. opuntiae* is outstanding for its distribution, a number of hosts and biotypes (Chávez-Moreno *et al*., 2010).

In areas of intensive *Opuntia* cultivation, *D. opuntiae* is mostly controlled with chemical insecticides (Badii and Flores, 2001). These measures, however, can negatively affect humans (García *et al*., 2003; Rinsky *et al*., 2013), the environment and ecologically important insects, such as pollinators and natural enemies (Ripper, 1956; Guez *et al*., 2005). All these points to the need to search for a native predator to implement in a *D. opuntiae* management program. The greatest richness of natural enemies of *D. opuntiae* has been reported in Mexico (Portillo and Vigueras, 2006; Rodríguez-Leyva *et al*., 2010), where there are at least seven predators in prickly pear crops (Vanegas-Rico *et al*., 2010) and others that are occasionally present in natural and urban areas (Vanegas-Rico *et al*., 2015). Understanding of this system is limited. Which predators might be the most efficient, as well as the effect of abiotic factors on predator and pest populations, is unknown. For this reason, our objective was to study population dynamics of *D. opuntiae* and of its natural enemies and the effect of abiotic factors on their populations.

MATERIALS AND METHOD

Area and period of study. Collections were done in Tlalnepantla, Morelos (18° 57' N and 98° 14' W), the second largest *O. ficus-indica* cactus-producing region. These crops have a vertical homogeneous architecture formed by a few strata (up to four) to increase plant density. In this area, three commercial plantations were selected, each approximately 0.5 ha, identified as L1, L2 and L3, located at altitudes of 1741, 1848 and 2105 m, respectively. In L1, a solution of soap-malathion was applied at the end of June, while in L2 and L3 the growers visited the plantations sporadically to fertilize occasionally (different kinds of manure and in unknown proportions) and harvest the young cladodes (nopalitos). During the period from August to December 2008 in L2 and L3, organophosphate insecticides were applied and sanitary pruning was carried out to eliminate the pest from the crop and renew production in 2009.

Field samples. The population dynamics of *D. opuntiae* and its natural enemies was registered for 28 consecutive weeks, from February to August 2008. The rest of the year was omitted to reduce the variability caused by frequent insecticide application. The borders of the plantations (approximately 3 m) were excluded from sampling. On each date, ten random plants per plantation were examined, and one cladode of each was selected at random to extract five mature colonies of *D. opuntiae* (50 colonies per plantation and 150 per sampling). Each colony was isolated in a labeled Petri dish (Ø= 2.5 cm). When density and proximity of the colonies made it difficult to distinguish boundaries, specimens were collected from a circular area 2.5 cm in diameter with a recipient of the same diameter. The population dynamics of the predators is described with the immature stages (larvae or pupae) since they remain with the colonies of their prey, developing on and below them (Vanegas-Rico *et al*., 2010).

Dactylopius opuntiae infestation was estimated with the mixed scale proposed by Vanegas-Rico *et al*. (2010), which was modified to obtain percentages of the cladode surface covered by *D. opuntiae*: 1 = up to 25 %, 2 = 26-50 %, 3 = 51-75 % and 4 = > 75 %. The distribution of the insects in each plant stratum was recorded: as level 1, the rooted cladodes, and as level 2, those that grow on level 1 cladodes, and so forth.

The *D. opuntiae* colonies were taken to the Biological Control Laboratory of the Colegio de Postgrauduados, Texcoco, State of Mexico, for processing, which included counts of female *D. opuntiae* and of natural enemies per colony. Specimens of adult cochineal females and recently emerged predators were processed for their identification using taxonomic keys and comparison with specimens of the reference collection, determined by specialists [See Vanegas-Rico *et al*. (2010)] in natural enemies of

Dactylopius spp. at the Colegio de Postgraduados.

Climate data. In plots L1 and L2 temperature (ºC) and relative humidity (% RH) were recorded with a portable hydrothermal unit LE-USB-2© (Lascar Electronics, USA). In L3, data from the "Galileo" weather station (FUPROMOR, 2009), located at 19°01'08'' N, 98°99'65'' W and 2082 m. Daily precipitation, maximum intensity and number of days with rain were obtained from this weather station and were considered representative for the three plantations.

Data analysis. Population dynamics was described with the two evaluated variables of *D. opuntiae* (level of infestation and number of females/colony) and average values (individuals/colony) of the most abundant natural enemies. The registers of each plantation were considered replications. A partial Pearson correlation analysis (Statistix, ver. 8.0 Analytical Software, USA, 2003) was performed between the insect populations of each locality and abiotic factors. Moreover, the distribution of the insects in the plant profile was compared with an ANOVA and separation of means with Tukey p = 0.05 (SPSS statistics ver. 22, IBM, USA). Finally, t-student tests (SPSS statistics ver. 22, IBM, USA) were conducted to compare the abundance of each species relative to the vertical position of each cladode (strata 1 to 4) during the rainy season with that in the dry season.

RESULTS AND DISCUSSION

Wild prickly pear cochineal *D. opuntiae* was present during the entire sampling period. In the 4200 colonies evaluated, 3795 immature predators belonging to eight species (Table 1) were collected. Four were frequent and accounted for 99.2 % of the total individuals: *Leucopis bellula* Williston, 1889 (39.3), *Sympherobius barberi* (Banks), 1903 (35.6), *Laetilia coccidivora* (Comstock), 1879 (15.7) and *Hyperaspis trifurcata* Schaeffer, 1905 (8.6 %). The rest had an abundance of ≤ 25 individuals. These species were reported previously in this cactus-producing region by Vanegas-Rico *et al*. (2010).

Population dynamics. The level of infestation and number of adult females/*D. opuntiae* colony had similar fluctuations (Fig. 1a). Initial infestation was ≈50 % of the cladode area with 6.13 ± 0.2 females/colony. Infestation increased to its maximum (levels 3-4, ≥ 75 %) in week 18 when 12.4 ± 0.4 females/colony were recorded. In later weeks, it descended gradually until the end of July (level 1 ≤ 25 %), and recovering in the second half of August with ≈75 % and 6.3 ± 0.2 females/colony (Fig. 1a).

In neither of the variables evaluated was the distribution of *D. opuntiae* homogeneous in the vertical profile of the plant ($F_3 \geq 17.8$, $p = 0.00$). When infestation began, the cochineal was collected more frequently in the lowest cladodes (rooted) and population density increased gradually colonizing the upper strata as temperatures increased. 80 % of the colonies evaluated developed in the second (27.3 %) and third (52.7 %) strata; the other 20 % was distributed in the first and fourth strata. The latter was the commercial cladode or "nopalito". This vertical distribution changed as precipitation increased, and in later months the presence of colonies on the first cladode increased (Figs. 2a and b). During the rainy season, there was a significant reduction in infestation (t = -6.7, df = 48, $p < 0.00$) and in females/colony (t = -3.9, df = 48, $p < 0.00$), relative to the dry season. This reduction was significant for both variables in the second (t = 4.7, df = 16 $p < 0.00$) and third strata (t = 4.1, df = 16 $p < 0.00$), an estimated reduction of 18 and 24 % in level of infestation and 31 and 27 % in number of females/colony.

The highest abundance of predators coincided with the highest density of their prey. Based on the curve type of their dynamics, two groups of natural enemies were established. The first group included *L. bellula* and S. *barberi*, whose population dynamics was bell-shaped (Fig. 1b). These predators were present on all of the sampling dates, and their relative abundance was 0.36 and 0.32, respectively. *L. bellula* had an incidence of 21.9% in the colonies evaluated and averaged 0.1 and 1 individual/colony (Fig. 1b). The brown lacewing *S. barberi* had an incidence of 19.8% and averaged 0.01 to 1.5 individuals/colony (Fig. 2b). The second group comprised *La. coccidivora* and *H. trifurcata*, whose populations dynamics did not have a defined

Table 1. Abundance of predators of *Dactylopius opuntiae* in three plantations of Tlalnepantla, Morelos, from February to August 2008.

Order/ Family		Species	Abundance Num. individuals/ (%)
Diptera	Chamaemyiidae	*Leucopis bellula* Williston	1,491 (39.3)
	Syrphidae	*Eosalpingogaster cochenillivora* (Güerin-Menéville)	25 (0.7)
Coleoptera	Coccinellidae	*Chilorus cacti* Linneo	2 (0.05)
		Hyperaspis trifurcata Schaeffer	325 (8.6)
		Scymnus louisianae Chapin	2 (0.05)
Lepidoptera	Pyralidae	*Laetilia coccidivora* (Comstock)	595 (15.7)
Neuroptera	Hemerobiidae	*Sympherobius angustus* (Banks)	3 (0.08)
		S. barberi (Banks)	1,352 (35.6)

form (Fig. 1c); *La. coccidivora* was present in 12.7 % of the colonies, while *H. trifurcata* was collected in only 6.3 % of the colonies. The values of both predators were low and fluctuated from 0.1 to 0.4 individuals/colony (Fig. 1c). Distribution of the enemies along the plant profile was homogeneous for *S. barberi* and *La. coccidivora* ($F_3 \geq 2.3$, $p \geq 0.6$), while *H. trifurcata* and *L. bellula* varied among the strata ($F_3 \geq 4.5$, $p \leq 0.005$), and more were present in the second and third strata (Figs. 3a and b).

Correlation between insect populations. Abundance of the four predators correlated positively with the number of *D. opuntiae* female adults/colony: *L. bellula* ($r = 0.5999$, $p < 0.0001$), *S. barberi* ($r = 0.5359$, $p < 0.0001$), *La. coccidivora* ($r = 0.4007$, $p = 0.0004$), and *H. trifurcata* ($r = 0.3536$, $p = 0.0019$). Correlation between these predators and the level of prey infestation was significant and positive only for *S. barberi* ($r = 0.3931$, $p = 0.0005$) and *L. bellula* ($r = 0.3075$, $p = 0.0073$) (Table 1). Correlations between predators had positive values, except among *L. bellula* and *La. coccidivora*, and the highest correlation value was between *L. bellula* and *S. barberi* ($r = 0.5822$, $p < 0.0001$); a higher incidence (≈50%) of *S. barberi* was registered in the colonies when *L. bellula* was present.

Correlation between insect populations and abiotic factors. The number of females/colony had a higher positive correlation with mean temperature ($r = 0.39$, $p = 0.01$). In contrast, the level of infestation had a negative correlation with R.H. ($r = -0.5648$, $p < 0.0001$) and number of days with rainfall ($r = -0.5621$, $p = 0.0189$) (Table 2).

The predators, with the exception of *L. bellula*, correlated positively with minimum temperature ($r \geq 0.42$, $p = 0.00$), and only *La. coccidivora*

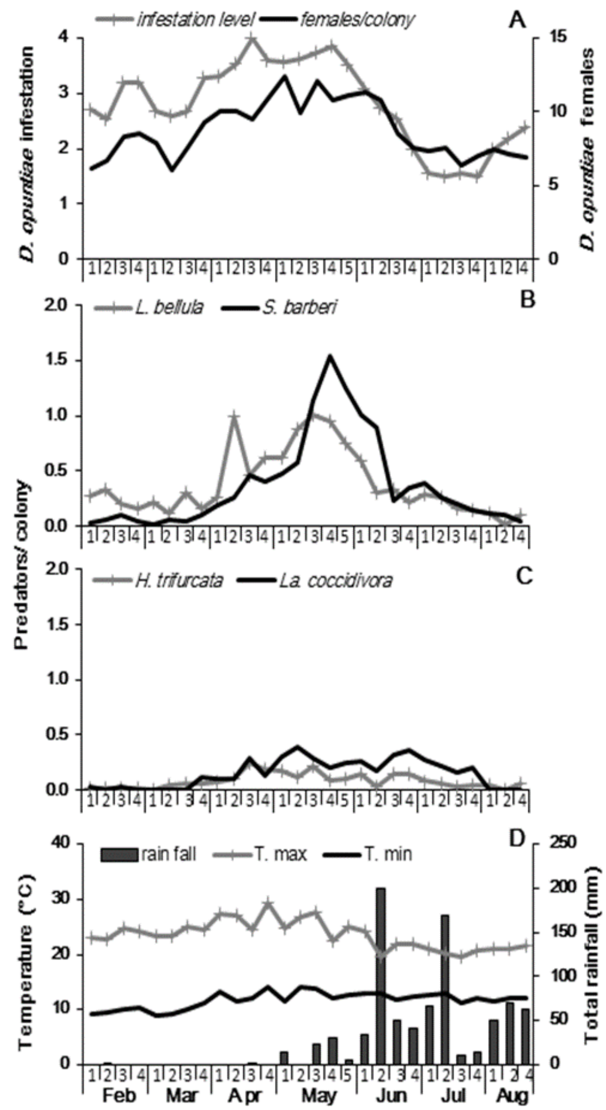
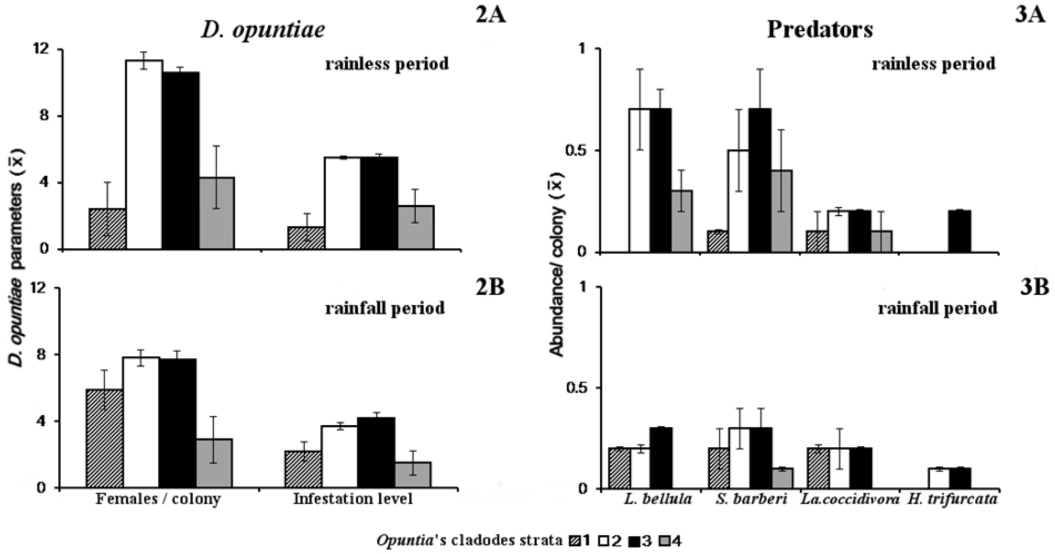


Figure 1. Population dynamics of *Dactylopius opuntiae* and its natural enemies and abiotic factors in Tlalnepantla, Morelos, Mexico. A) Level of *D. opuntiae* infestation and number of adult females/colony. B) The most abundant and frequent predators: *Leucopis bellula* and *Sympherobius barberi*. C) Less abundant predators: *Laetilia coccidivora* and *Hyperaspis trifurcata*. D) Abiotic factors: Temperature and precipitation.



Figures. 2 and 3. Distribution of insects in the plant strata in two periods: rainless and rainy. 2a) females/colony and level of *Dactylopius opuntiae* infestation in the drought season. 2b) females/colony and level of *D. opuntiae* infestation in the rainy season. 3a) predator abundance/colony in the drought season. 3b) abundance of predators/colony in the rainy season. The *Opuntia* of Tlalnepantla had four strata, the first is rooted, the rest grow consecutively on the previous stratum; stratum 4 is the level of the youngest cladodes harvested for commercial purposes.

Table 2. Pearson correlation indexes between estimated parameters of *Dactylopius opuntiae*, its natural enemies, and abiotic factors in *Opuntia* plantations in Tlalnepantla, Morelos, Mexico.

		D. opuntiae		Predators			
		infestation	*Females/ colony*	*L. bellula*	*S. barberi*	*L. coccidivora*	*H. trifurcata*
Predators							
L. bellula	*r* =	0.40	0.54				
	p =	(0.00)	(0.00)				
S. barberi	*r* =	0.31	0.60	0.58			
	p =	(0.01)	(0.00)	(0.00)			
L. coccidivora	*r* =	---	0.40	---	0.41		
	p =		(0.00)		(0.00)		
H. trifurcata	*r* =	---	0.35	0.29	0.25	0.51	
	p =		(0.00)	(0.01)	(0.03)	(0.00)	
Abiotic factors							
T. min.	*r* =	---	0.35	---	0.42	0.75	0.56
	p =		(0.01)		(0.00)	(0.00)	(0.00)
T. med	*r* =	---	0.39	---	---	0.49	0.55
	p =		(0.00)			(0.00)	(0.00)
T. max	*r* =	---	0.33	---	---	0.31	0.44
	p =		(0.01)			(0.03)	(0.00)
R. H.	*r* =	-0.56	---	---	---	0.37	---
	p =	(0.00)				(0.01)	
D_pp	*r* =	-0.56	---	-0.48	---	---	-0.58
	p =	(0.02)		(0.05)			(0.02)

correlated with R.H. (r = 0.37, p = 0.01). The species *L. bellula* and *H. trifurcata* correlated negatively with the number of days with rain (r = -0.48 and -0.58, respectively, $p \leq 0.05$) (Table 1).

The decrease in the abundance of each predator/colony was more notable in the second (69%) and third strata (65%); in both cases the reduction was significant ($t \geq 2.1$, df = 16, $p \leq 0.04$).

Dactylopius opuntiae incidence and infestation in *Opuntia* plantations in Tlalnepantla, Morelos, occur in function of different factors, among which temperature has a positive effect on development of *Dactylopius* species (Moran and Cabby, 1979; Hosking, 1984; Sullivan, 1990; Méndez *et al*., 1995). In contrast, the rainy season and subsequent increase in R.H. have a negative effect on the abundance and vertical distribution of *D. opuntiae*, as has been mentioned for other species of this family (Marín and Cisneros, 1983; Moran and Hoffman, 1987; Moran *et. al*., 1987; Sullivan, 1990). This occurs as an effect of the more exposed cladodes getting knocked off (Moran *et al*., 1987), the friction of raindrops that reduce the waxy cover of these insects making them more exposed to predation (Marín and Cisneros, 1983) and too stressed to regulate their temperature by evaporation of water (May, 1985).

The distribution of the pest found in the evaluated plots is representative of the nopal-growing region. Presence of mature *D. opuntiae* colonies in the four strata suggests neglect or abandonment, since nopalitos are a commercial product. In general, the greatest abundance of *D. opuntiae* is found in the second and third strata, and variations in these two strata could be due to, besides rain, nutritional differences by effect of plant maturation (Rodríguez-García *et al*., 2007).

Registers of colonies in the first stratum occur not only because of the influence of climate but also as a consequence of management since the residues of sanitary pruning are frequently deposited in or around the plantations. Some of the discarded cladodes produce roots, thus favoring the permanence of *D. opuntiae* in the crop. At the end of the rainy season and insecticide applications, the surviving colonies colonize the first stratum for refuge during the winter and remain there until the beginning of the next hot dry season. This condition is generalized in prickly pear nopalito crops of Mexico (personal observation).

Population fluctuations of the four most abundant predators, *L. bellula*, *La. coccidivora*, *H. trifurcata* and *S. barberi*, correlated positively with fluctuations in the population of their prey (Table 1). In those correlation tests the predators *L. bellula* and *S. barberi* stood out, although these values were not high enough; however, similarity in the abundance curves of these two predators relative to that of their prey, suggests a very closely related population response. It is likely that this association also occurs in other climatic conditions and with other Dactylopiidae species. In California, these two species were recognized for their abundance in colonies of *D. confusus* (Goeden *et al*., 1967). Immature populations of *L. bellula* develop under the colonies, feeding on eggs and nymphs I, while *S. barberi* remains under the colony during the larva I stage and has greater activity over the colonies where they prey on all the cochineal instars (Vanegas-Rico *et al*., 2010). Although this may suggest a probable compatibility as agents of biological control, in other prickly pear plantations of Mexico, *Sympherobius* sp. larvae have been recorded preying on *L. bellula* and *H. trifurcata* larvae (Vanegas-Rico, unpublished data). These observations did not determine whether this conduct was circumstantial or common ethology to cover nutritional requirements since it has been reported that a diet of *D. opuntiae* nymphs I is insufficient to maintain immature populations of *S. barberi* (Pacheco-Rueda *et al*., 2011).

Hyperaspis trifurcata was the least abundant predator of the four. Its immature populations were absent in the first five samplings, even when adults were observed during the entire study. It is known that other species of the genus *Hyperaspis* do not synchronize with their prey (Kiyindou *et al*., 1990); their fecundity responds more to prey with a mixed population structure (Reyd and Le Rü, 1992; Vanegas-Rico *et al*., 2016). It is likely that the presence of eggs and nymphs assures survival of their offspring. Other factors such as inhibition of oviposition by intraspecific competitors or the existence of parasitoids that emerge from larvae and pupae of this coccinellidae in Mexico (Vanegas-Rico *et al*., 2015) and in Texas, USA (Gilreath and Smith, 1985) should not be ruled out.

In terms of abundance and degree of association of *La. coccidivora*, our study contrasted with the studies conducted in Mexico State (Cruz-Rodríguez *et al*., 2016) and Texas (Gilreath and Smith, 1988), where this species was considered an important predator of *D. opuntiae* and *D. confusus*, respectively. This is explained in part by the prolonged low or null chemical scenario in both works, and the period in which the second authors conducted their study: from May to November *La. coccidivora* is more abundant in the USA (Powell, 1980).

The predator has been observed during periods of high infestation, monopolizing most of the colonies by forming silk tunnels, which apparently reduces impact of rain on immature populations. The registers of their dynamics contribute to this argument since it was the predator that had a lower, but non-significant, population decrease (a maximum of -13%) in the rainy season (Figs. 3a and b), relative to that in the dry season (t = 0.55, df =16, p = 0.59).

CONCLUSIONS

Dactylopius opuntiae appeared in the prickly pear nopalito crops in Tlalnepantla, Morelos, during the entire sampling period. Its abundance and distribution in the plant profile varied over time and occurred in function of abiotic conditions: temperature (+), rainfall (-) and R.H. (-). In general, the indexes of correlation between the insect populations and abiotic factors had moderate to low values (0.3053 to 0.7464), because population abundances are also influenced by other factors not evaluated in this study, such as agronomic practices (use of insecticides, weed control, fertilization and cladode pruning), as well as parasitoids of the predators and possibly interspecific competition for the food resource and oviposition sites. Under the conditions of the area and period of this study, the abundance of *L. bellula* and *S. barberi* accounted for 70% of the total number of predators, and their populations were synchronized with that of their prey. Based on the results of this study, we suggest that future laboratory studies should focus on the species *L. bellula*. Finally, the knowledge presented of *D. opuntiae* population fluctuations can contribute to developing management actions for this intensive crop during the winter when populations are low and localized in the lower part of the plant.

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