Article

Interaction of environmental factors and natural enemies with populations of *Aulacaspis tubercularis* Newstead in Nayarit, Mexico

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Abstract

The objective of this study was to know the population dynamics of the white mango scale, *Aulacaspis tubercularis* Newstead at different temperatures and determine the relationships between climate factors and natural enemies with the populations of the scale. The study was conducted in 2013-2014 on seven mango thefts (*Manguifera indica* L.) of the Ataulfo cultivar, located in places with different temperatures in San Blas, Nayarit. In each orchard, populations of white scales and their insect predators were recorded every two weeks. Variance analyzes were carried out to compare the populations between sampling dates and localities; correlations were also obtained between temperature, rainfall and the complex of predators with the populations of the pest. The highest population levels of the white scale of mango were recorded during the period with higher temperatures and without rainfall (April-June); in contrast, during the period with rainfall, the population in all orchards was scarce or nonexistent. A positive correlation of the temperature was determined with the population of the white scale of the mango, in such a way that the increase of the temperature during the year favored the increase of the populations of the pest. In contrast, rainfall negatively impacted the pest by drastically reducing the density of its populations. Finally, the increase of the populations of the scale favored the increase of the population density of the complex of predators of the plague.

Keywords: *Aulacaspis tubercularis*, Ataulfo cultivar, white mango scale.

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Introduction

The mango (*Mangifera indica* L.) is one of the most important fruits of the tropical and subtropical zones of the world. Mexico ranks fifth in terms of total mango production (FAOSTAT, 2018), with an established area of more than 200 thousand ha and a production of 1 223 800 t (SIAP, 2018). The main producing states are Guerrero, Nayarit, Sinaloa, Oaxaca, Chiapas, Michoacán, Veracruz, Jalisco, Colima, Campeche and Tamaulipas. This fruit is attacked by important insects such as mango white scale (EBM), *Aulacaspis tubercularis* Newstead (Hemiptera: Diaspididae) (Urías-López and Flores-Canales, 2005, Urías-López *et al*., 2010) and others such as fruit flies of the genus *Anastrepha* (Urías, 2006; Urías-López *et al*., 2016a).

The EBM is one of the main pests of the crop because by harming the fruits (Urías-López *et al*., 2010, Abo-Shanab 2012), it can affect up to 100% of the production, as is the case of the cultivator Keitt (Urías-López *et al*., 2016c). The plague was detected in Nayarit, Mexico in 1999, by the end of 2009 it had spread to almost all mango producing municipalities in the state and affected an area greater than 13 thousand ha (56% of the surface) (Figueroa-De la Rosa *et al*., 2008; Isiordia-Aquino *et al*., 2011; García-Álvarez *et al*., 2014). Currently, EBM is established in almost all coastal states of the Pacific, where mango is produced, as well as in the producing areas of the Gulf of Mexico (González-Acuña *et al*., 2016).

It is considered that several factors determine the abundance of EBM, including temperature and rainfall, as indicated by some studies on the distribution of the pest in Nayarit (Urías-López *et al*., 2010; García-Álvarez *et al*., 2014), as well as their natural enemies (Urías-López *et al*., 2016b). Regarding climate factors, the highest averages of scale infestation correspond to plantations located at low altitude, possibly due to the effect of temperature (Urías-López *et al*., 2010; Isiordia-Aquino *et al*., 2011; García-Álvarez *et al*., 2014). It has been determined that the populations of the EBM are lower during the rainy season (July-September), with a period of population growth from December to February and the highest population densities occur during the dry and warmer season of the year, from March to the beginning of rain in June (Urías-López *et al*., 2010; García-Álvarez *et al*., 2014; Balderas-Palacios *et al*., 2017). The EBM infestations occur in greater proportion in the cultivars Tommy Atkins, Ataulfo and Haden (Urías-López and Flores-Canales, 2005, Urías-López *et al*., 2010).

Regarding biological control, several predators and scale parasitoids have been recorded; for example, in South Africa Labuschagne (1993), has detected *Auleurodothrips fasciapennis* Franklin and *Aspidiotiphagus citrinus* Craw as the most important; in Israel occurs *Coccophagus lycimnia* Walker, *C. eritraensis* Compere, *C. scutellaris* Dalman, *C. bivittatus* Compere, *Microterys flavus* Howard and *Metaphicus flavus* Howard as parasitoids of EBM (Kfir and Rosen, 1980). In Nayarit, the only parasitoid of EBM that has been identified is *Encarsia citrina* (Urias, 2006; Urías-López *et al*., 2016b). Also in Nayarit several predators have been observed, such as the 'cargabasura' *Ceraeochrysa* spp., *Leucochrysa* sp., *Chrysoperla externa* Hagen, the coccinellids, *Chilocorus cacti* L., *Azya orbigera* Mulsan, *Pentilia* sp. (González, *et al*., 2010; Urías-López *et al*., 2016b) and the *Scymnus* sp. and *Stethorus* (Urías-López *et al*., 2016b).

It has been indicated about the modification of environmental conditions, in particular temperature and rainfall (Netherer and Schopf, 2010), which could generate changes in the development of populations and displacement of various pests and diseases to other places. Due to the importance of the white scale as a mango pest, as well as climatic factors and natural enemies in the regulation of pest populations, the present study was proposed in order to know the population dynamics of the white scale of the mango at different temperatures and determine the relationships that exist between climatic factors such as temperature and rainfall, as well as natural enemies with populations of white scale in the cultivar 'Ataulfo' in Nayarit.

Materials and methods

Location of the study area

The study was conducted from April 2013 to March 2014, in seven commercial orchards of the cultivar 'Ataulfo' in the municipality of San Blas, Nayarit. This municipality is located between parallels 21° 20´and 21° 45' north latitude, meridians 105° 01' and 105° 28' west longitude, with an altitude between 0 and 1 200 meters above sea level (Table 1). Localities located at different heights above sea level were selected to have orchards with different temperatures, so they were chosen from the sea level (Miramar) to the maximum approximate height where the crop is grown (Puerto de Linda Vista) in Nayarit

Table 1. Location of experimental mango orchards in Nayarit[1].

Location	Altitude (m)	Geographic location
Miramar	25	N 21º25'43.7", W 105º11'03.8"
El Cora	180	N 21º26'35.3", W 108º08'19.2"
Tecuitata	340	N 21º27'44.5", W 105º07'48.9"
Jalcocotan	405	N 21º28'29.4", W 105º06'18.9"
Mecatan	527	N 21º30'06.5", W 105º05'24.1"
Jalcocotan 2	616	N 21º 31'09.2", W 105º 07'34"
Pto. de Linda Vista	821	N 21º31'40.1", W 105º02'47.1"

[1]= the maximum distance between the orchards, from Miramar to Puerto de Linda, was only 15 km.

Sampling of white scales and their predators

During the study, the selected orchards were not subject to pest control. For the EBM sampling, the methodology suggested by Urías *et al.* (2010), in each orchard five trees were marked to estimate every 15 days the populations of the pest. Four shoots per tree were selected from each tree, one at each cardinal point and from each shoot two leaves were sampled, eight leaves per tree, for a total of 40 per orchard. On each side of the leaf the number of females and colonies (formed by males) was counted, in order to estimate the total number of scales (females plus colonies). For the sampling of natural enemies, the same trees selected for the scale count were used. In each of the four selected branches (approximately the last 50 cm of each branch), the total of predatory insects of each species was counted.

In each orchard, a portable sensor was installed (data loggers HOBO Pro v2 model U23-001) to record the temperature. The rainfall data of the area were obtained from the climatological station of INIFAP, located in Las Palmas municipality of San Blas, Nay. The monthly averages of temperature and the monthly total of the rainfall were used to determine correlations with the populations of the scale. The experimental orchards were selected almost in a straight line and there was only a distance of 15 km between the first orchard (Miramar) and the last (P. de Linda Vista).

Statistical analysis

The data of the EBM and climatic parameters were processed by analysis of variance of the variables under study, with design in random blocks with five repetitions (trees), using the statistical package of SAS Institute (2010). For each locality, the data of the populations of the EBM or of the predatory species of insects were compared between dates of sampling, or between localities. For comparison of means, the Tukey test ($p \leq 0.05$) was used. From each locality, correlations were obtained between temperature, rainfall and total predators, with the EBM populations.

Results and discussion

Climate information

Climatic data showed that the orchards located in El Cora and Miramar were the warmest during the year, with averages of 24.3 and 24.4 ºC, respectively, while the least warm was the Puerto de Linda Vista orchard with an average of 20.3 ºC (Table 2). The orchard located at sea level (Miramar) was 3.8 ºC warmer than the one of maximum height. Rainfall in the area where experimental orchards are established was 191, 308.8, 467.4, 357 and 17.4 mm, corresponding to the months of June, July, August, September and October respectively. Due to the location of the orchards and the short distance (15 km) between the first and the last, it is assumed that the rainfall was approximately similar for all.

Table 2. Average monthly temperatures in experimental mango orchards. Nayarit, 2013-2014.

Month	Miramar	El Cora	Tecuitata	Jalcocotan	Mecatan	Jalcocotan 2	P. de L. Vista
June	27.4	26.6	26	26.7	24.9	24.5	23.1
July	27.7	26.6	25.9	25.2	24.6	24.3	22.5
August	27.7	27	26	25.3	24.7	24.3	22.7
September	26.7	26.8	25.1	24.4	24.5	24.1	22.1
October	26.9	25.9	26.3	25.3	24	23.6	22.2
November	24.8	24.9	23.9	23.2	22.5	22.2	20.3
December	21.9	22.3	21.2	20.6	20	20.1	17.9
January	20.9	21.6	19.7	20	19.4	19.3	17.4
February	21.1	21.1	20.9	20.9	19.8	20	17.5
March	21.5	22.3	21.4	21.9	20.6	21.1	18.3
April	22.7	23.8	22.8	22.4	22.3	23.1	20.5
May	26	25.2	24.6	23.8	21.9	23.8	21.6
Average	24.28	24.41	23.42	22.98	22.21	22.34	20.27
Altitude (masl)	25	180	340	405	527	616	821

Population dynamics of the scale

The trend in the variation of white scale populations during the year was very similar in all orchards, with only difference in the magnitude of them. Due to the above, only the data of two contrasting orchards, Miramar (orchard of lower height) and Puerto de Linda Vista (the highest one) are presented, as well as the average of the seven orchards of the populations during the year (Figure 1-3). Three periods occurred in the population dynamics of the plague; the first from April to June, in general, it was the period with the largest population of scales, and it occurred during the dry season and with high temperatures (April-June).

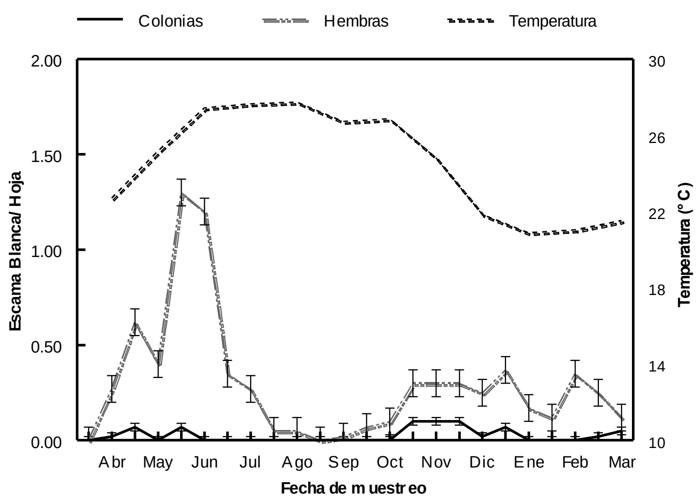

Figure 1. Population density of the white scale of the mango. Miramar, Nayarit 2013-2014.

During this period in the Miramar orchards, the scale populations surpassed 0.5 leaf scales, with the highest recorded value of 1.5 scales per leaf (Figure 1). It was also detected in the lowest period, or without the presence of scale, during July and October, in the period of high temperatures and with summer rains. In this year, a third period was also detected from October to March of population growth or in which the density of the populations remained at low levels, with an average below 0.5 leaf scales (females plus leaf colonies) (Figures 1 and 2). This population distribution of white scale in individual orchards is reflected in a very similar way as the average of the seven orchards (Figure 3). Again, the highest populations were detected from April to June, the lowest during the rainy season between July and October.

Similar results were obtained by Urías-López *et al*. (2010), pointing to a stage of very low populations during the rains from July to October. In this case, in the periods without rain, the populations of white scale increased significantly with the increases in temperature, as indicated previously (Urías-López *et al*. 2010; Bautista-Rosales *et al*., 2013; García-Álvarez *et al*., 2014). These authors recorded an increase in white scale populations from March to the beginning of the rains (stage of mooring of fruit and harvest).

On the other hand, Arías *et al*. (2004) states that *A. tubercularis* remains in branches and leaves and at the beginning of the dry season (flowering and fruiting), the populations increase and migrate towards the fruits where they cause important injuries. In this study, it is suggested that there is a clear effect of temperature on the populations of the EBM because in the period with the highest temperatures, but without rain, it was when the highest population densities were reached. During the rainy season, high temperatures were also recorded, but the scale populations decreased considerably. According to Urías-López *et al*. (2010), the reduction of EBM populations during this period is due to a drastic effect of the rain, which probably due to mechanical effect affects the most vulnerable stage (of walkers) of the scale, as recorded in this study (Figure 1-3), which represents the lowest populations of EBM in each of the study orchards.

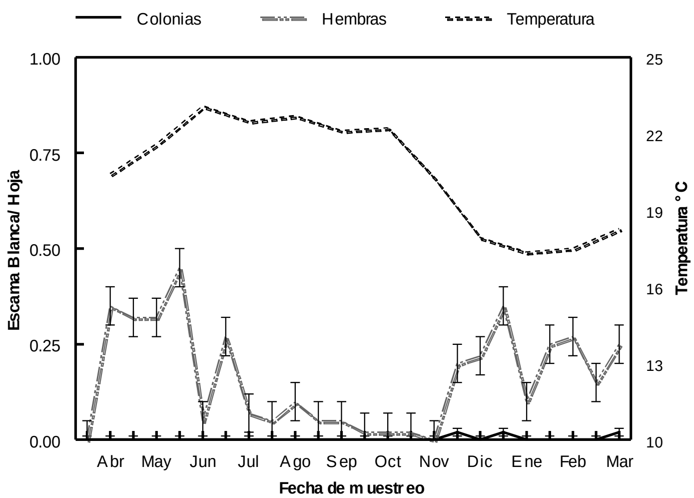

Figure 2. Population density of the white scale of mango. Pto. Linda Vista, Nay. 2013-2014.

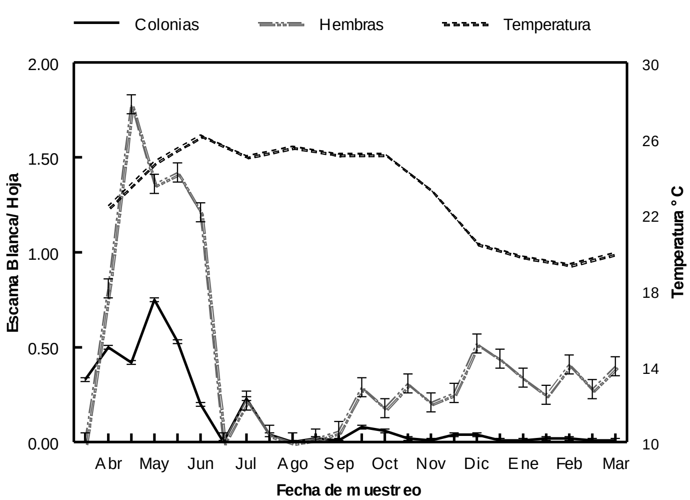

Figure 3. Population density of the white scale of seven mango orchards. Nayarit, 2013-2014.

Average densities of the white scale population during the year

The analysis of variance showed significant differences among localities in the total average density of the EBM during the year. The seven sampling locations also showed differences in the abundance of females and colony of the scale. The Jalcocotan orchard presented the highest density of scales in comparison to the other localities, with a total annual average of 0.4 scale-leaves (Table 3), while in the orchards of Miramar and Mecatan the highest populations of colonies (males) with 0.03 leaf-colonies. The lowest averages of populations of white scale appeared in the locality of Puerto de Linda Vista, that corresponds to the orchard less warm (Table2), with a total annual average of 0.18 scale-leaf (Table 3).

Table 3. Population density (±EE)[1] of the white scale of the mango. Nayarit, 2013-2014.

Location	Temperature	Colonies	Females	Total
Jalcocotan	22.98	0.02 (0.004) ab	0.38 (0.01) a	0.40 (0.01) a
Miramar	24.28	0.03 (0.004) a	0.32 (0.01) b	0.34 (0.01) b
Mecatán	22.21	0.03 (0.004) a	0.30 (0.01) b	0.33 (0.01) bc
Jalcocotán 2	22.34	0.02 (0.004) ab	0.30 (0.01) b	0.32 (0.01) bc
El Cora	24.41	0.01 (0.004) bc	0.28 (0.01) b	0.29 (0.01) cd
Tecuitata	23.34	0.02 (0.004) ab	0.22 (0.01) c	0.24 (0.01) d
P. de Linda Vista	20.27	0.003 (0.004) c	0.17 (0.01) d	0.18 (0.01) e

Vertical values with the same letter are not significantly different (Tukey, $p \leq 0.05$). The values are the average of seven orchards and 24 samplings per orchard during a year; [1]= Standard error.

Therefore, it is suggested that there is an effect of temperature on the populations of the EBM, since in general terms, the highest populations of the EBM occurred in the orchards with the highest average temperature during the year and the lowest in the orchards with lower temperature. This effect could be related to the reduction of the life cycle and increase of the reproductive rate of EBM.

Populations of predators of white scale

In the mango trees, several species of natural scale predators were detected, such as the coccinellids *Pentillia* spp., a complex of *Stethorus* spp., and *Scymnus* spp. and another one of 'cargabasuras' (*Ceraeochrysa* spp.). The larvae complex of 'cargabasura' (*Ceraeochrysa* sp.), were those that were detected in the largest number of orchards (Table 4). The highest average annual density of 'load-bearing' was recorded in the El Cora, Nay orchard. (0.035 larvae-branch) and the lowest in the Tecuitata (0.004 larvae-branch). Regarding the total number of predatory species of the EBM, the greatest number occurred in the orchards of Mecatan, El Cora, Jalcocotan and Jalcocotan 2. In the orchards of Miramar, P. de Linda Vista and Tecuitata, barely perceptible total population levels were recorded, with a total average no greater than 0.012 predators-branch (Table 4).

In other studies conducted on beneficial insects of EBM in several Mexican states (González-Carrillo *et al*., 2010; Urías-López *et al*., 2016b), they also found a complex of predator species such as 'cargabasura', *Ceraeochrysa* sp. (Neuroptera: Chrysopidae), adults of *Pentillia* sp., *Stethorus* sp. and *Scymnus* sp. (Coleoptera: Coccinelidae). The results of the present study indicate that in general, predatory insects were an important factor in the regulation of the population of EBM, because it was notorious that the females of the scale were always present in greater quantity than the colonies, probably due to the action of its predators.

Table 4. Average population density (± EE) of predators of the white scale of mango. Nayarit, 2013-2014.

Location	*Pentillia* spp.	*Stethorus* spp. and *Scymnus* spp.	*Ceraeochrysa* spp.	Total
Mecatan	0.006 (0.02) ab	0 (0.001) b	0.029 (0.01) ab	0.035 (0.01) a
El Cora	0 (0.02) b	0 (0.001) b	0.035 (0.01) a	0.035 (0.01) a
Jalcocotan	0 (0.02) b	0.008 (0.001) a	0.027 (0.01) abc	0.035 (0.01) a
Jalcocotan 2	0.008 (0.02) a	0 (0.001) b	0.025 (0.01) abc	0.033 (0.01) a
Miramar	0 (0.02) b	0.004 (0.001) ab	0.008 (0.01) cd	0.012 (0.01) b
P. de Linda Vista	0 (0.02) b	0 (0.001) b	0.009 (0.01) bcd	0.009 (0.01) b
Tecuitata	0 (0.02) b	0 (0.001) b	0.004 (0.01) d	0.004 (0.01) b

Vertical values with the same letter are not significantly different (Tukey, $p \leq 0.05$). The values are the average of seven orchards and 24 samplings per orchard during a year. [1]= Standard error.

On the other hand, it is probable that the differences in density of the population of the scale between localities are not due only to the effect of the predators, since, although it is true, the highest populations of these also occurred in the Orchards with higher populations of scale and vice versa, populations of predators in general, occurred at very low densities compared to those recorded by González-Carrillo *et al*. (2010) and probably were not a factor to mark differences in population densities of the scale between orchards. Due to the above, although it was notorious that the high populations of scales favored an increase of the populations of the predators, the differences in the populations of the EBM between orchards, were due mainly to the effect of the temperature and rainfall, as it is appreciated with the results of the correlations (Table 5).

Table 5. Correlations between temperature, rainfall and predators with the population density of *Aulacaspis tubercularis*. Nayarit, 2013-2014.

Location	Temperature		Rainfall		Predators	
	r^2	p	r^2	p	r^2	p
Miramar	0.8154	0.0136	-0.1903	0.5535	0.1911	0.5518
El Cora	0.6287	0.045	-0.3267	0.3	0.2681	0.3995
Tecuitata	0.1989	0.669	-0.7166	0.0087	0.1533	0.1998
Jalcocotan	0.4952	0.2585	-0.5649	0.0456	0.7521	0.0048
Mecatan	0.6763	0.1402	-0.5649	0.0456	-0.217	0.4981
Jalcocotan 2	-0.1532	0.7424	-0.7978	0.0019	0.4393	0.153
P. de Linda Vista	0.1681	0.6907	-0.6142	0.0336	0.0275	0.9323
Average	0.3961	0.004	-0.4527	0.0001	0.3166	0.0034

Correlations between climatic factors and predators with white scale populations

A positive correlation was observed between the temperature and the white scale populations in the sampling orchards, except in the Jalcocotan 2 orchard. However, this correlation was only significant in the Miramar and Camino al Cora orchards. In the case of rainfall, a negative correlation was detected with the population density of the scale; this correlation was significant in most of the orchards, except in the orchards of Miramar and El Cora. On the other hand, the correlation between the population density of the scale and the population density of predators was positive and significant only in the case of Jalcocotan, Nayarit (Table 5).

With respect to the average of all orchards, the correlation between temperature and the annual population density of the scale was also positive and significant. In this same sense, the correlation rainfall with the population density of the EBM was negative and significant. In the case of predators, a significant correlation was found with the population density of the EBM (Table 5). The results of this study indicate that, within the temperature limits prevailing in mango orchards, it has a positive impact on the populations of scale, that is to say as the temperature increases, the density of the population of the scale it also increases.

Conversely, rainfall had a negative effect on the population density of the scale, so that, during periods of rain, the density levels of the pest are reduced. In the case of natural enemies, the result of the correlation indicates a dense dependent factor, since the population density of the predators increases as the populations of the EBM increase.

The results of the correlation between the variables, considering each of the orchards, were inconsistent. This is probably because, at the orchard level, the interaction of the factors is more important to modify the populations of the scale than to the effect separately from any of them, therefore, only a correlation of that factor can be detected. It is dominant specifically in that orchard. On the other hand, when considering the global average of the population densities of the EBM of all the orchards, with the factors analyzed, the results were much more consistent.

Taking into account this last observation, it can be concluded that high temperatures are an important factor in the regulation of the population of the scale, favoring the increase of its population density during the warmer periods. However, with the temperatures registered in the orchards during this study, these were not sufficiently low to totally knock down the populations of the EBM in Nayarit.

On the other hand, rainfall is also an important factor that negatively affected the population of the scale during periods of rain. As the frequency by orchard of significant correlation of rainfall was higher than that detected with temperature, rainfall was more important than temperature to abate scale populations. Because there was no consistent correlation at the orchard level between the density of the populations of the scale and that of the predators, it may be that in this study, the populations of the scale and predators were relatively low compared to the detected by Urías-López *et al*. (2016b).

Conclusions

According to the results of this study, it is concluded that the increase in temperature during the year favored the increase of EBM populations. In contrast, the rainfall negatively impacted the scale, drastically reducing its population density. Finally, the increase in the population density of the EBM, caused an increase in the population density of the complex of predatory insects that attack this pest.

Acknowledgments

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